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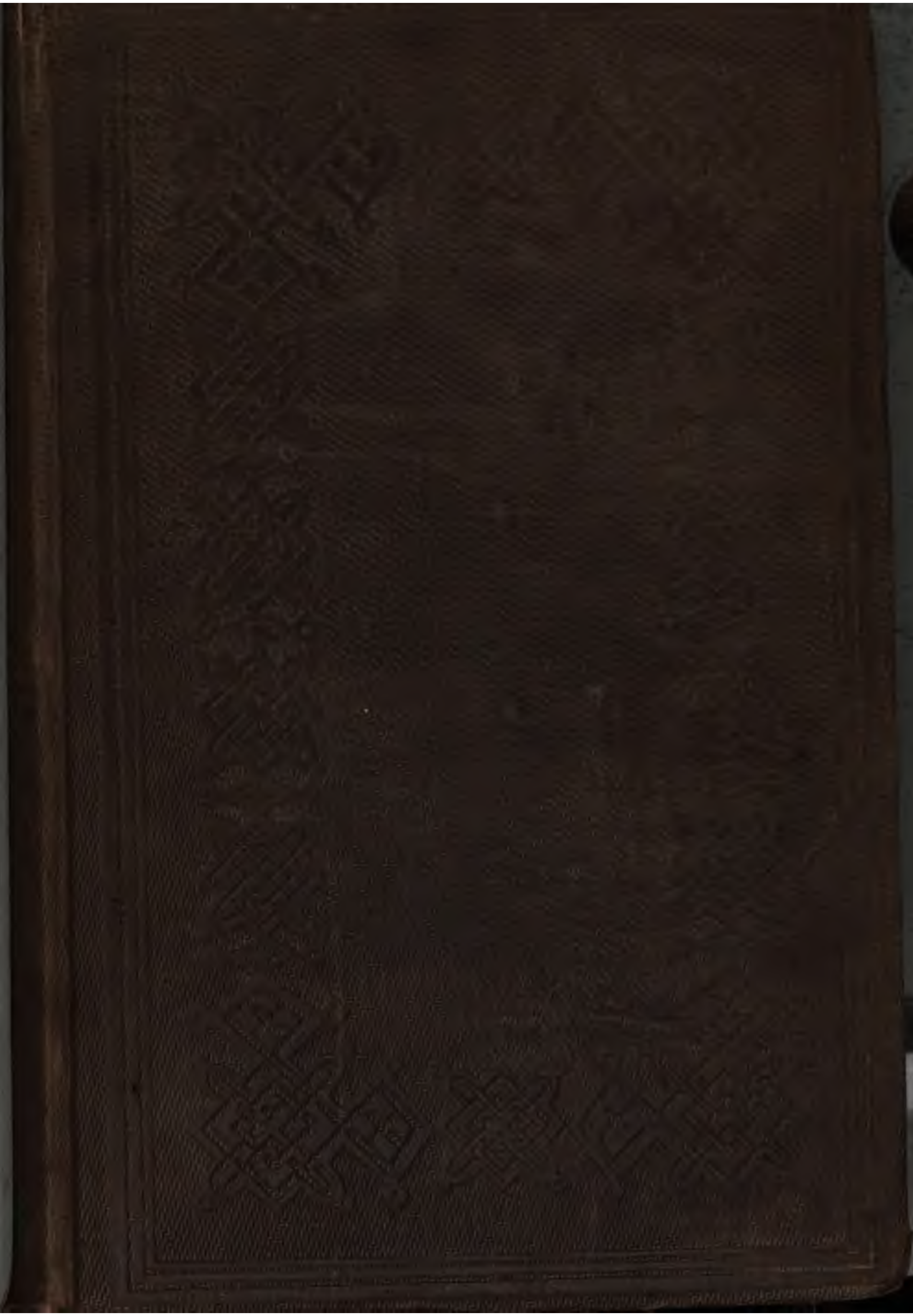

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MINING, AND GENERAL AND PARTICULAR METALLURGICAL OPERATIONS,

WITH A DESCRIPTION OF

CHARCOAL, COKE, AND ANTHRACITE FURNACES,
BLAST MACHINES,
HOT BLAST, FORGE HAMMERS, ROLLING MILLS, ETC. ETC.

JOHN HEWSTON JR

BY FREDERICK OVERMAN,
MINING ENGINEER.
AUTHOR OF A "TREATISE ON IRON," ETC., ETC.

WITH THREE HUNDRED AND SEVENTY-SEVEN WOOD ENGRAVINGS.

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PUBLISHERS' PREFACE.

THIS work is chiefly designed to present a practical view of the various and extensive operations of Metallurgy. It is not, however, merely a description of processes, and an enumeration of facts, which would be of comparatively limited importance to the active and inquiring mind of the public; but each division contains a philosophical investigation of the apparatus used, and the operations performed, in all specific cases, as well as the principles upon which their advantages depend. Without entering so extensively into scientific considerations as to impart, in any degree, the character of a theoretical work to his book, the author has, nevertheless, amply enriched his pages with all such investigations as were necessary for the elucidation of the principles involved in these extensive pursuits.

The progress of the work through the press was somewhat interrupted by the death of the author, when two-thirds of it had been put in type. The manuscript, however, had been previously completed by him, with the exception of the last chapter, which has been added chiefly from APPLETONS' DICTIONARY OF MECHANICAL SCIENCE. In all other parts, it is entirely the work of Mr. Overman. There may, perhaps, be instances in which he is more or less indebted to the labors of other writers, in these pages. If such is the case, it would have, undoubtedly, been acknowledged, had he lived to write this notice.

The reader may discover imperfections, and even errors, in the work; and doubtless the author would have been fearful that such existed, if he had witnessed its completion. To this apprehension, he would, unquestionably, have alluded in a similar manner to which he has done in a former work, and which we take the liberty here to quote.—"It may even embody errors; these, on the ground of human frailty, may be deemed by the kind-hearted reader excusable. The expression of one fact will, we hope, disarm critics. We make no claims as a writer. We make this statement not only because the language of the book is not our native tongue, but because, though it were, we doubt whether we should be able to exhibit a reasonable proficiency in its use."

The following tribute to the memory of a worthy and accomplished man of science, is from the pen of a personal friend of Mr. Overman. It is presumed that its insertion here will prove not otherwise than agreeable to the reader, while it will impart gratification to the author's friends.

"Frederick Overman died on the 7th January, 1852, in Philadelphia, at the age of 49 years, from the effects of arsenited hydrogen, inhaled while engaged in a chemical analysis. He was a native of Germany, and born in Elberfeldt of humble parents, who could give him but the rudiments of a common school education; and when a boy, bound him to learn the mercantile business. This employment, however, little suited his taste and natural activity, and he bound himself afterwards to a cabinet-maker, in whose business he acquired a proficiency. While thus engaged and acquiring habits of industry, he was sedulously employed to gain knowledge and to enrich his mind. Endowed by nature with a vast cerebral organization, indeed one of the very first order, and with a decided preponderance of the higher faculties, the yearnings of such a mind could not be permanently kept under by poverty and opposing outward circumstances. He began to travel, as all mechanics do in Germany, and went to Berlin to work. There he succeeded in obtaining an admission as a pupil of the Royal Polytechnic Institute, the first institution of its kind in Europe, and then under the superintendence of the celebrated Mr. Beuth, who was not long in discovering the pre-eminent talents of his pupil, and consequently took an especial interest in the education of the young man. He remained in that Institute I believe four years, during which time he also attended lectures in the Royal University, and was also by his protector introduced to the unions of the first artists and scientific men of the age, as for instance Professor Rauch the celebrated sculptor, Schinkel the great architect, Alexander von Humboldt, &c. It was under the spell of such happy and ennobling influences, that Frederick Overman acquired such a deep and abiding love of scientific pursuits, and cultivated his taste of the fine arts. Those who have been intimate with the deceased, appreciated his exquisite taste and mature judgment in all that is ennobling and beautiful. In his mind there was a rare union of the ideal with the useful, the practical and the rational. But the most prominent trait in his character was an exalted love of truth and moral freedom, those two features essential to form the basis of a really great man. But few persons in this country have been on terms of intimacy with the late Mr. Overman, and by many of his superficial acquaintances he has been either misunderstood or not at all comprehended. Such deep and great natures can never accommodate themselves to the superficialities of our unnatural social institutions, they can never be dragged down to the quagmire of competitive strife and hatred. In his scientific and technological researches he would pursue his object with indefatigable industry only so long as the scientific interest, or the interest of the inventor was kept alive. This once satisfied, he would drop that pursuit, no matter how great the prospects of emolument and profit. This is the test of true genius. He will never exert himself without a noble object in view! The day may yet come, when human nature will be more appreciated, and when society will be so constituted, that the ordinary wants of nature's noblemen will be provided for, so that they may be at liberty to follow the bent of their genius, without being harassed by petty cares! While in Europe, Mr. Overman moved in useful and extensive spheres. His improvements in the manufacture of iron have given him a reputation. In this branch of technology he has labored successfully a number of years; he was well paid, and his engagements called him to all parts of Europe, where he introduced his improvements in the process of puddling and other manufactures.

He has been engaged in superintending the erection of various large manufacturing establishments; he conducted at one time the extensive engineering establishment at Chemnitz, in Saxony; and for a period was in the employment of the Austrian Government, working under the especial and personal charge of Prince Metternich, for the purpose of ascertaining the industrial resources of the empire, and collecting commercial data upon which to found the basis of a new commercial treaty with Great Britain. All these engagements were but of a temporary duration; his strong love of freedom and unfettered action would never permit him to accept of a permanent situation as a government official, neither in Austria nor Prussia. His political instincts were thoroughly democratic. Various disappointments and dissatisfaction induced him to emigrate from Germany to this country, in the year 1842, where he has been variously employed in introducing improvements in the manufacture of iron. In this he has met with success and failures. Had he enjoyed the good fortune of a James Watt, in finding another Bolton, who had appreciated his talents, and applied his inventive genius to mercantile use, he could have realized fortunes. For the last three or four years he was engaged principally in his technological writings. His work on the manufacture of iron is highly appreciated in Great Britain, and by the London Mining Journal is pronounced the best scientific treatise ever published on the subject.

JOHN A. ROEBLING,
Civil Engineer.

TRENTON, N. J., *7th April,* 1852.

The Publishers, amid all the circumstances, have spared neither labor nor expense to render this work such as might be expected, from the extensive importance of the subject, and the ability of its author. They anticipate that its practical information will be found in advance of similar works. And although it might have been better, if it could have received the benefits of the author's revision throughout, yet they are confident it will meet with that favor from the public which is due to the last labor of one who has passed beyond the sphere of human criticism.

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METALLURGY.

PART FIRST.

MINING

CHAPTER I.

Exploring.—In order to obtain those minerals which form valuable metals in the course of metallurgical operations, we must first find the ores. These, however plentifully distributed over the globe, must be sought by intelligent inquiry, if their discovery is not made accidentally. Any heavy material on the surface of the globe is a metallic ore, an oxide or compound of some metal; we may with propriety range potash, lime and clay, magnesia and silex among the metallic ores. At the present time we use only some few metals in the arts, but it does not follow from this that sodium and others are excluded for ever from being useful. The time may come when calcium will be as valuable as any other metal. Those ores which are useful in our operations of manufacturing metals, are seldom found on the surface of the earth; they are in most instances buried beneath the soil, and penetrate the solid rock often to considerable depth. Some may be found on the surface, at least those which are insoluble in water, as all the oxides of iron; but not so the carbonates, and the sulphurets. As iron is distributed in every part of the earth's surface, as it has affinity for all other matter, and as it is insoluble in water, we may expect to find it in every locality where we explore for ore. Iron ore appears in so great a variety of forms, it is often so far blended with other matter, that we are justified in asserting that it represents almost all the known varieties of other ores in appearance; it is frequently so disguised as to make an assay necessary in order to recognize its presence.

In most instances, when we find a heavy mineral, our first thought should be that it is iron; and if, after a rigid examination, we find it is not iron, we are at liberty to infer another kind of ore. Iron is very plentiful in our country; it is hardly worth the pains and time taken to hunt for the ore. Its value is so small, it does not pay more than the expenses of digging and hauling in the majority of instances.

We may expect to find iron every where—in ploughing, in making roads, and in digging canals. It is not so with other ores. Gold, if in its metallic state, may be found in the soil and in the ravines where a gentle current has accumulated alluvial deposit. Is the soil or sand composed of clay and other substances, and light, so as to form readily soft mud, we always find the gold lying deep, on the face of the rock; particularly if the gold is coarse. It is in vain to look for fine gold in the bed of a river: its place is in the soil, and ditches made by the gentle currents of rain-water. Metallic gold cannot be found in the coal regions; it belongs to an older period of creation. At the time when coal was deposited, it was too wet and cold for its formation, and that which may possibly have been liberated by abrasion of the old rocks, was rubbed to fine invisible dust, which probably may exist in all rocks of the younger series. Gold is soluble in sulphurets, wherein is an excess of sulphur: we find gold, therefore, in all pyriteous ores, particularly in those of iron, copper, and lead; but the quantities are often so small, that its value would not pay the expenses of extraction. We may find gold in the pyrites of all the Atlantic States, but, to all appearances, the near approach of coal is the cause of its being in small quantities in those States. In Virginia and North Carolina we find coal near the gold ore deposits, and even in the belt of the gold-bearing rocks; but that coal is a secondary deposit, the gold rock was formed before the coal was deposited—it underlays the coal. In the western bituminous coal-fields, it is of no use to look for gold. Along the lakes there may be gold, but we are not informed of its having been found in sufficient quantity for extraction. Both slopes of the Rocky Mountains are the legitimate localities for gold deposits. Gold is often found in tertiary formations, in lignite and the rocks around it, but is of no practical use. If we suspect gold, either in alluvial soil or in rocks, the surest way to discover it is to wash the matter—that is, remove the rocky matter by water in a manner described hereafter, and if the particles of gold are so heavy as to remain after the debris of rock is removed, the ore may be useful. If the particles of gold are so small as to float away with the rocky matter, the ore is of no use. Pyrites are tested by means of the assay. Near limestone rock, no gold is found.

Copper ore is in most instances recognized by its green color: if the body of the ore, in the interior, is blue, or red, or black, that on the surface contains always more or less of the green kind; and we are generally correct in supposing copper where green silicious matter is found.

Lead is not often discovered on the surface of the ground, or imbedded in the soil: freshets may expose a vein of galena and carry particles away from the general deposit, but this is no rule. Galena is easily decomposed by the atmosphere, and as the resulting sulphate, or carbonate, or oxide, is very light, and in the form of dust, it is easily carried away by currents of water. Deposits of galena must be looked for in steep hills and rapid currents, in limestone rock and the old slate, in graywacke, gneiss and porphyry; but in all stratified rocks of the coal series, and the younger rocks, it is in vain to look for it. There may be lead ores—such as carbonates, sulphates, and others in young formations—but we have such an abundance of good galena, which will keep the price of lead down, that the manufacture of that metal from any other ore is unprofitable. If, therefore, other ore is found, it is of little value for smelting lead; but it may be valuable for silver or gold, provided it contains so much of the precious metals as to pay for their extraction without depending on the amount of lead. Galena is easily recognized by its metallic lustre and cubical crystals; that of the slate formations contains always more precious metals than that from the limestone rocks.

Silver is generally a companion of lead, and it is not often found in any other form than combined with galena. In native copper, particularly that found at Lake Superior, there is in many instances a large quantity of metallic silver. Such ores, however, cannot be considered silver ores, for we cannot extract the silver without incurring heavy expenses. Silver occurs also in antimony, but always combined with lead. If we find an ore accidentally, and it is not in a compact vein in the old or igneous rocks, we may doubt its being a useful silver ore; if it comes from a limestone region, it is generally very poor in silver. We are therefore not justified in expecting to find silver ore in alluvial soil, or young rocks.

All other ores form compounds, or are found in a form which is easily destroyed. Neither zinc in all its forms, nor antimony, tin, or arsenic can be expected to appear at the surface; we must look for them either in crevices or upon the rock below the soil. The presence of an ore may be presumed where a specimen is found, or where fine particles of it occur. If this should be on a hill-side, the deposit or vein must be sought higher up than where the specimen is met with; so, likewise, if it is in a creek or river, the deposit must be sought higher up, either in a branch or on the river bank. If the specimen is found on a plain, the ore may lie beneath it, or it may be an accidental deposit, carried there by waters whose course cannot be traced. Such stray specimens are worthless, but if a large body is found, such as gold in alluvial gravel, we may expect to meet a deposit of the material somewhere in the surrounding mountains. These stray specimens, or, as they are often called, blossoms, are traced to their origin in the rock where they came from. A guide, in these instances, is to be found in the quality of the accompanying gravel, the side of the river on which it exists, and in its own composition. If it is found in a creek, or a river, it is traced so far as specimens are found in its bed; and if these indications cease, they come either from a branch, and must be looked for in that direction, or they are washed down from the river hills. In most cases of the latter kind, we find a rivulet, ditch, or drain, where the specimens come from. We then follow its course until we find in its ramifications an indication of the origin of the stray ore. Are the specimens deposited in the gravel of a river bank, it is always more difficult to find their source, particularly when the gravel is light, sandy, or muddy. In many instances we cannot trace the origin of the specimens. In the gravel of the Western rivers, in the coal-basins, we find specimens of granite, gneiss, and porphyry; rocks which are not found at the head-waters of these rivers and their ramifications, these are evidently travellers from far-off regions, carried to their present location by high floods, which cut out these valleys, and which originated in the polar regions. If such stray specimens are found in regions where the rocks cannot contain that mineral, it is a waste of time to search for a vein of it. If a piece of bituminous coal is found in the bank of the Connecticut river, we know it came there by accident; for the valleys or hills of the river and its tributaries may contain anthracite or lignite, they cannot contain bituminous coal. If a piece of gold is found in the gravel of the Ohio, it is no indication of a deposit somewhere in the vicinity. If specimens of galena were found on the western slope of the Alleghanies, we should be inclined to doubt the presence of a workable vein.

Is the course of the debris of an ore vein traced to its disappearance below the soil which covered the rock, on a hill-side, we may conclude the deposit is not far off. If it disappears in the alluvium of the valley, it may belong to a vein far away; and if the valley is large, and the gravel heavy, it is of no use looking for the ore bed. In heavy, loamy ground, there is a prospect of arriving at the deposit, but not generally without much digging. Where the last traces of the blossom disappear below ground we commence digging, and follow the course of the stray specimens. If no indications are found, we may distrust our being on the right track, and it is advisable to follow once more the original course of the guides. Is the deposit of ground heavy, we may conclude the vein is higher, for some fall is always required for the water to carry the specimens down hill, they never are lifted from below. Is the place where the blossoms disappear below ground, on a hill-side, the best plan is to follow the blossoms by digging after them, and if they are at a gently sloping hill, we find it more profitable to go as far up the hill as possible without losing the track, and dig a shaft down to the rock. If we meet the blossoms in this shaft, before we come to the rock, we are too low for the vein, and it is advisable to quit working in that shaft and commence digging a new one higher up the hill. This last shaft should strike the rock above, or at the vein. It is advisable to dig the first shaft a few feet deeper than the blossom of the ore, for it may happen the surface of the rock is near, and if this is the case the vein cannot be far off.

In following the indications of an ore deposit, we are always to distinguish between heavy and light ores, between friable and hard material. A piece of anthracite coal may be carried 500 miles, without losing much of its form; bituminous coal to a less distance, and lignite will bear still less travelling. Gold cannot be found far from its origin; heavy rains may carry it down a steep hill, but a river will not move it; or if it did, it would soon be destroyed, as it is rubbing constantly upon the rock, or between clean hard gravel on the bottom; and being very liable to abrasion, it is soon divided into small particles, which are floated off by the current. Even the most gentle motion of water will bear away fine particles of gold. Galena may be carried farther from the place of its origin than gold; it is not so heavy as that, and hard, but it is liable to be broken into small cubes, which are often extremely fine when found in the beds of the rivers. Useful iron ores are never carried far by a current, they are too tender to bear that kind of transport. Tin ores are often found in alluvial gravel, bedded upon rocks, but they seldom appear at the surface, except in old deposits, always protected by a layer of gravel. All other ores are too friable to be carried by such forces as water, and too oxidizable to resist the oxygen of the atmosphere for a long time. Where such specimens are found, there must be a vein near at hand.

Exploring by shafts.—When an ore deposit has been so far explored, as to show the nature of the vein, and the quality of the ore has been examined superficially, as to its value to the smelter, the vein is opened by penetrating farther into it. Sufficient room is now made to work the vein, and the whole thickness is cut out, for some extent. The amount of the vein taken out must be in proportion to the angle of the walls of the vein, that is, the rock on each side of it; are these parallel, that is, do they show no curves or divergence, we are justified in concluding the vein to be uniformly thick. A few yards, or from twelve to fifteen feet, are in most cases sufficient to investigate the character of a vein. Are the walls of the vein curved, or divergent in one or the other direction, we have to act more cautiously and continue to explore it. If the divergence increases rapidly, we may conclude the vein to be a lode or mass of more or less extent. In all cases it is necessary to expose the walls of both sides, so as to obtain a correct view of the inclination of the axis of the vein. The axis is that plane which is equidistant from the walls of the vein; and as this plane is not always straight, we divide it into a number of small straight planes, or convert it into a curved plane.

The conditions, under which the operations of exploring may be continued, must now be considered before proceeding any farther with the operation. The first consideration involved relates to the nature of the ore. It must be assayed as to its quality, and if an opportunity is afforded by smelt works, to test it on a large scale, at least some tons ought to be smelted; and if we want a thorough trial, one furnace ought to work this particular ore at least until all other ore and metals are tapped, and the trial ore is the only one in the furnace. This test smelting is necessary for iron, lead, copper, zinc, and similar ores. The value of the ores of precious metals can be ascertained by the assay, on a small quantity, with perfect certainty; also the value of mercury, nickel, and some others. In those cases where the value of the metal produced depends on its purity, a trial on the large scale never ought to be omitted. It is almost impossible to find a small quantity of phosphorus or sulphur in iron ore by the assay, while the quantity of that substance may be large enough to injure the quality of iron manufactured, so as to make it unsalable.

The next consideration is the price of ore, that is, the expenses of mining. If the vein or deposit is in alluvial soil, the body of ore and its direction will afford the means of ascertaining the amount of incumbent earth to be removed. The price at which this may be accomplished, reduced to one ton of ore, or any other measure we choose, forms the standard of dead work. If the vein is imbedded in rock, the expense will depend very much on the solidity and hardness of the ore itself; the price of digging it is, however, chiefly regulated by the undermining, and the thickness of the vein. If the vein is bedded upon a soft understratum, which may be easily penetrated by the pick, it shows to the best advantages to the miner for taking out the ore. This undermining is of the utmost importance, and in many instances determines the value of the vein. The best position for it is below the vein, between the rock and the vein; its thickness, if but two inches, is sufficient, three inches are better, and if thicker than that, there is no harm in it. The undermining may be in the middle of the vein, or at the top of it, or it may be in the rock above or below the vein; in all cases it forms the most important auxiliary to the miner; without it the work progresses but slowly, and must be expensive in consequence. The undermining may be a vein of soft clay, or clay slate, shale, carbonate of lime in stalactites, gravel, sand, or ore in a loose form; crevices in the vein, or water-courses near it. The nature of the adjoining rock has no influence upon the price of the ore; it bears only a proportional part on the whole amount of ore raised, so far as dead work is to be performed in it. The location of the vein forms another object of our consideration. If the vein is in low, marshy ground, the accumulation of water will be great, and the expenses of removing it considerable. If the vein is so located that the water above it may filtrate into the mine, and annoy the miner, it is a means of increasing the expenses of extraction. If the vein dips from the place of exploration it will accumulate water, and water-courses must be cut into the bed rock to remove it. The price of labor and the facility of procuring workmen, is an object to be well digested before forming the conclusions as to the cost at which the ore can be dug. In a populous country laborers may be had at any time, skilful miners, however, may be scarce, and the latter are as necessary to insure good success as any other item in the calculation. Good, sober workmen, perform always the cheapest labor; but these claim the comforts of civilization, and if we are to procure those comforts for them, it cannot be done without incurring expenses which are frequently neglected in the estimates by those who lay the plans of mining operations. The price of labor is or may be considered uniform over the United States, but it is evidently higher in the western and southern states than in the east and north. Nominally, the wages paid are higher in the latter parts of the Union, but really, the labor performed is cheaper; the workmen do more work, and do it better than in the south and west of the Union. The labor in the Pacific states and territories is at present high, and rich mineral deposits only will pay the expenses necessarily connected with mining operations in them. This state of things, however, is temporary, and will disappear in the course of a few years, provided they possess lasting mineral treasures. Fuel is in most instances an important item in determining the value of an ore deposit. Gold deposits, in alluvial ground, or where it is found in abundance in the metallic state in veins, does not require much fuel for its production. The supply for a steam engine is in most cases all that is required, but even this is in many instances an important item of expense. Zinc requires a large amount, and therefore cheap fuel. Iron requires less, but still a cheap fuel. In the production of lead and other metals, there is less objection to using expensive combustibles. The price and quality of timber is often a large item of expenditure in mining operations; in extensive and heavy lodes, in friable rock, and damp mines, the wood does not last long, and much is required. Pine wood is by far more expensive than leaf wood, because of its brief durability. The facilities for transportation, or the proximity of smelt works, or a market, is an object generally well understood by our citizens, and needs only to be mentioned as an active agent in determining the value of a mine. All these considerations taken together, form the basis for estimating the price of ore, and the value of a mine.

The price of a ton of ore, for which we assume 2240 pounds, avoirdupois, is regulated by the market for it, or by the smelt works. Gold ores, which appear in the form of ferruginous slates, free from adhesive clay and not too hard, may be crushed and amalgamated; in fact the metal obtained from it, at an expense of one dollar per ton in the mill, driven by a steam engine. The quantity of gold in such ores is therefore the means by which to determine the value of the mine. If we subtract one dollar from the actual quantity of gold in a ton of rock, for the necessary expenses, we obtain the value of the remaining gold which is to pay for raising the ore. If the ore contains much clay it impedes the progress of work in the mill, and $1 50 may be set down as mill expenses. If the ore contains iron or copper pyrites, a large quantity of quicksilver is lost in amalgamation, which may increase the expenses to $2 and more. The presence of lead and other metals of similar nature increase the mill expenses, because mercury is absorbed by these metals and lost. The mill expenses constitute a necessary and unavoidable outlay, and these are the first items to be considered; the remaining quantity of metal must pay the expenses of mining, the interest on the capital invested, and furnish the profits. If the veins of gold ore are composed of a soft slate, such kind as most of the Virginia mines show, and are so thick as to admit of a man standing upright to work in them, a ton of ore can be dug at from 60 to 75 cents average wages; to which amount dead work and interest on capital is to be added. If the vein is composed of hard rock, such as some of the vitrified magnesia slate and quartz veins of North Carolina and Georgia, the price of mining increases from $1 to $3, and more. Is the vein thin, so that a part of the dead rock is to be taken out in order to admit the miner, the cost of working the rock increases the expenses of the ore, and must be taken into account. A man may dig a ton of soft slate at 50 cents, hard slate at $1 to $3, and hard quartz, porphyry or stratified gneiss, at $2 to $6. The general expenses, such as dead work, pumping, hoisting, ventilating, and others, are proportioned to the whole amount of ore taken out of the deposit and calculated per ton; of this we shall speak hereafter. Open digging and an injudicious method of work may produce cheap ore for a certain time, but it infallibly increases the expenses of extraction rapidly with the depth, and generally encumbers a mine for ever. Skilfully conducted work below ground is always the cheapest in the course of time; it causes more expenses than open work at first, but these, when appropriated to the body of ore, are generally found to be very small, and soon are repaid by the superior advantages accruing to the miner, and by the facilities it affords in employing steam or water power to assist the miner in removing the ore and the water.

The expenses for producing a ton of pig iron in the smelt works are from $10 to $15, exclusive of interest on capital invested. The latter generally increases the cost to the amount of $1 50 to $2. If the price of pig iron is $20, and the smelting costs $11 50, the ore necessary for a ton of iron may cost $8 50, which price, however, would give no profit to the smelter, and no fund for incidental expenses. Two tons of rich magnetic ore can produce a ton of iron; this kind of ore may therefore cost $4 a ton. Three tons of good hematite, or red oxide, are in most cases required for making a ton of iron, and such ore should not cost more than $2 66. The poor hematites, bog ores, and poor ores generally, do not furnish more than 25 per cent. of metal, and such ore cannot be worth more than $2 per ton. The price of pig iron varies according to quality; it is higher for charcoal than for anthracite and coke iron, and higher for cold than hot-blast iron. But this does not enhance the value of the ore, because these are items which increase or diminish the cost of smelting. On an average we may assume, that if a ton of rich magnetic ore costs more than $4 at the smelt works, good hematite more than $3, and poor ores more than $1 50 or $2, they are too expensive for our iron manufacturers.

The price of lead ore at the Missouri lead mines varies from $20 to $40 per ton. The smelters buy it at that rate. The latter price is not generally paid, and $30 may be considered the average for clean ore. If the ore veins happen to be strong, the miners make good wages; but the business is not so remunerating as to insure large profits. The smelt works yield but little, and so the miners suffer. If mining was carried on here with judgment and capital, the price of the ore might be reduced considerably, but there is little prospect at present for such investments. The expense of smelting a ton of lead from good ore amounts to about $15; and if incidental expenses and interest on capital are considered, it may be estimated at $20. If the price of metallic lead is $3 at the smelt works per hundred pounds, it will bring a ton to $66, from which the smelting is to be deducted; the remainder is for ore and profit. Galena will yield about 60 per cent of lead when pure, this makes more than 1.5 tons of ore necessary for one ton of metal, and if the ore is as high as $30, it leaves but little or no profit to the smelter.

Copper ores sell at a uniform price at the smelt-works, and $2 50 per cent. and per ton is the average price paid for ores. That is, a ton of ore which contains 10 per cent. of copper, and is free from injurious metals, such as lead, pays $25 at the furnaces.

Other ores than those mentioned are uncertain in their value; the amount of metal does not directly influence their price. It is the admixture of other matter which has the most decided bearing upon their valuation. We shall refer to these ores in their proper places; and also allude to the value of coal and combustibles, in the chapters assigned to these various subjects.

Examination of the Deposit.—Such considerations as the foregoing, determine if the miner is to proceed any farther, or drop the enterprise. If it is concluded to proceed, the next step is to ascertain the mass, position, and extent of the vein; this examination is in all instances tedious, slow, and in some cases expensive. The form of the ore deposit may be a mass—that is, a large, irregular-shaped nodule, of more or less extent; it is then an irregular heap, rounded or oval; it may extend for miles, or only for a few yards; its plane or largest extension, may be horizontal, inclined, or vertical. These deposits are generally found in alluvial soil, in beds of clay, or shale, in the old unstratified rocks, and on the surface of the ground. The iron mountain of Missouri, the hematite ores of Alabama, Tennessee, Eastern Pennsylvania, and other ores, appear in that form. These are mineral masses detached, to all appearances, from other masses. They send no veins, no ramifications into the rocks around. The form of the ore vein may again be a lode, or a flattened mass, of more or less extent; it may terminate in almost sharp edges at its apparent terminations, but these are always found to be small veins, connecting it with another lode; it is in fact a vein in an irregular form. A lode may run parallel with the strata of the rock, or cross these strata; it may penetrate unstratified rock, and cross in its extension and course other mineral veins, and other lodes. A lode may extend horizontally, or vertically, or may traverse the rock in any degree of inclination to the horizon, or to the strata of the rock. These forms and masses of ore, are often deranged in their supposed course, indicated by observing but a small part of it; they often dwindle into small veins, or divide themselves into a number of small veins: these modifications are generally caused by the rock in which the lode is imbedded. Lodes are characterized by distinct marks from the rock, and may be traced, even by the accompanying matter, distinctly, which latter possesses always distinguishing features. Pyriteous ores appear chiefly in lodes, and all sulphurets may be supposed to have their origin at and in the primitive rocks. Lodes are, therefore, very valuable forms of minerals, and it is of great importance to the miner to investigate, before he goes to work, if his mine is a part of a detached mass, or a lode. Veins appear in a more regular form than lodes; their position is more definite, and either parallel with the strata in which they occur, or cross these at certain angles in a manner more distinct and regular than lodes or masses. Coal deposits appear in veins, very seldom in masses, not at all in lodes. The gold ores of the Southern States are found in veins. Pockets, concretions or nodules, are small detached masses of minerals, which, generally are soon exhausted. Pockets are formed by gold, lead, and silver ores; nodules are found in the coal series, forming spheroidal masses of iron ore. Galena is found in concretions, pockets, lodes, and masses; but the latter are not frequent.

In order to determine the form of the deposit, it is necessary to open a certain portion of the ground, and even explore its supposed edge; open the vein in various places, and arrive in that way at a definite conclusion. It is of great importance to know the form of the mineral mass; it is not sufficient to investigate its inclination and direction, for the plan of working a mass is quite different from that of working a vein, or extracting the contents of pockets. When a vein or mineral deposit has been so far opened as to show its general direction and inclination, we measure the first by the magnetic needle, and the latter by the plumb-line or the level. In case any doubt is entertained as to the continuance of the form of the vein, which it shows so far as is explored, it ought to be opened farther in order to satisfy our mind as to its direction.

The operations connected with the investigation of an ore deposit, are similar to those of surveying, and the same instruments which serve for that purpose may be used in this instance. We perform all the operations of the surveyor, and find besides the inclination of the deposit. If the extent of the vein, in the mean time, is to be investigated, we need a measure; for which purpose any tape or silk string can be used. A wooden rod, or a chain measure, or a yard tape, may be also used. Generally a surveyor's chain of four rods, or sixty feet long, is used. Besides the chain, there are needed measuring pins made of iron, about ten inches long, having an eye at one end, on which they are strung to an iron ring or leather strap. Two staves are also required; these should be at least six feet long, mounted at one end with sharp-pointed iron so as to penetrate the ground readily; these staves hold the ends of the chain. The theodolite is often used to measure the inclination and direction of the vein; but as this instrument cannot well be applied below ground, a more simple one is used. The theodolite, however, is a convenient instrument above ground, and where large tracts are to be measured it is profitable to use it in preference to the following one. It would lead us too far if we were to extend our researches to the uses of the theodolite. An instrument more adapted for service below ground, and serving equally well above ground is the level and suspension compass.

FIG. 1.

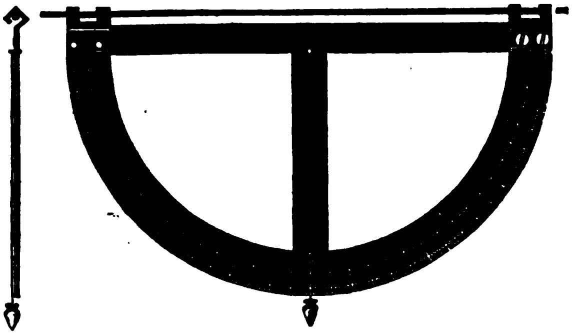


Fig. 1, represents a level which is also used for measuring the horizontal and the vertical angles. It is a half-circle, made of thin sheet brass, and is shown in half its usual size. The two hooks, which must be bent in a sharp angle at the points of suspension, are screwed to the semicircle, and the edges of these must form a perfectly parallel line with the diameter of the circle. The instrument represents a common protractor, with the addition of the hooks, the plumb-line, and the bob. The point for fastening the plumb-line must be exactly in the centre of the diameter, and a strong hair line is preferable to a silk string. In measuring angles this semicircle is suspended on a silk string, which is drawn in the direction of the axis of the vein.

The next instrument for the mining engineer is the suspension compass; it is represented in figs. 2 and 3 in half its usual size. These instruments ought not to be too small, or their indications are not very correct. Fig. 2 shows a similar semicircle as the level, fig. 1, but here is no division; the silk string on which the instrument is suspended is held in the direction of the vein, and the magnetic needle in the compass indicates the deviation of the vein from the magnetic meridian.

Fig. 2.

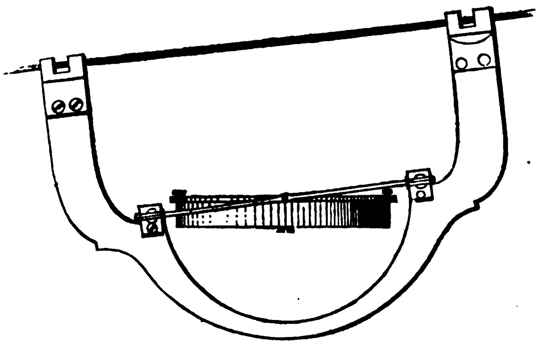
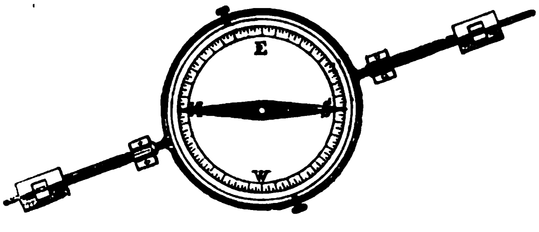


Fig. 3, shows this instrument from above. The compass being suspended in a universal joint, will admit of any motion in any direction, and be always horizontal, so as to indicate the true magnetic meridian, as soon as the needle is at rest. In observing a series of lines below or above ground, we arrive at the

Fig. .



general direction of the course of the vein. These instruments are particularly useful below ground.

A third instrument is required in order to draw the plan of a mine, and its extent on paper.

FIG. 4.

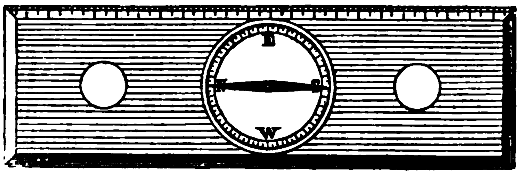


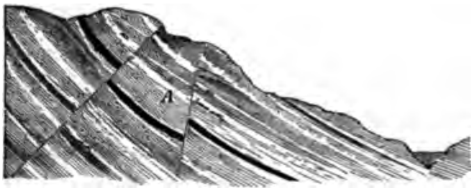
Fig. 4, represents the plan compass; it is a plate of brass, of about ⅛ of an inch thick, from 8 to 10 inches long, and 3 or 3·5 inches wide. The edges are tapered down so as to form a ruler's edge, along which a pen may be drawn. This instrument is laid on the paper on which the plan is to be drawn, and serves for marking those angles and distances noted in the pocket-book. The longitudinal axis of the ruler must of course correspond with the north and south direction of the compass, which is also the case in the suspension compass, where it falls in a line with the silk string on which it is suspended. One of the edges of this ruler may be divided in feet, or decimals of feet, and the other in duodecimals, so as to afford a convenient scale for the plan to be drawn.

When a mineral vein has been opened so far as to show its direction and inclination, we take the first by means of the suspension compass. If we draw a silk string, or a string of any other material, in the direction of the vein, we obtain the deviation of that direction from the magnetic meridian; this deviation is noted in a note-book, for reference. The inclination is obtained by stretching the string on which the level is suspended parallel with the walls of the vein, and in taking the middle of the divergence we obtain the axis of the vein. The inclination is of course calculated perpendicularly upon the direction of the vein: both directions are at right angles. Are both inclination and direction of the vein noted, we proceed above-ground and mark here the spot where the vein ought to crop out, in case it extended to the surface. This is the starting point, and from here all those investigations commence which are to lead to the examination of the deposit. Are the walls of the vein level, then the plane of its axis is level, and the vein has an horizontal extension, and if the out-crop of the vein is above the water-level of the ground, we may readily trace its outlines, by measuring from the water-courses, or running a level by means of the instrument. In this operation there is no need to be very particular, for such veins never run very straight, in the indicated direction. At intervals, which may be chosen arbitrarily, or at convenience, indicated by the locality, such as steep slopes, where not much ground is to be removed, we dig for the vein again, and ascertain if its direction, indicated by the first exposure, is correct. If we do not find it here, it will be necessary to expose the rock in both places, in order to obtain the nature of that above and below the vein. The farther we expose this rock, the greater probability for success in our following investigations. The nature of the rock indicates the approach of the vein. This remark applies only to stratified rocks, and veins which run parallel with the strata of the rock; such as coal veins, the iron ore veins of the coal region, and the gold ore veins of Virginia. Is the vein, indicated by the first opening, not found in the expected place, we return to the first spot, and open the ground nearer to the first exposure, enlarging in this manner on the direction of the vein. It happens quite frequently that a part of a vein indicates a certain direction which is not at all verified by subsequent examinations; this alludes particularly to lodes and masses. In making the openings close together, we may follow the track of a vein easily, and in marking the directions of the various exposures connected, in their relation to the meridian and horizon, we soon find out if the vein runs in a straight or more or less inclined plane, or if its plane is curved. If an out-crop is largely exposed on the surface then we may calculate with probability on its extension in the interior in a similar manner as its exterior, which rule, however, is modified by various circumstances.

Is the inclination of a vein vertical, or nearly so, we may trace its direction above ground with ease and certainty, provided the plane of the vein is straight,—if the latter is curved we are to investigate the curvature before we obtain a correct form for laying down a plan of operation. These veins are generally valuable deposits, for they extend in a comparatively small surface deep below ground, and form a large area. If these veins are an injection from below, such as those of the sulphurets or pyriteous ores, they generally afford a great depth, the end of which, in no case, has been reached by any mine. Veins of this kind very seldom run quite perpendicular; they are in most cases more or less inclined, and in almost all instances curved. Such veins frequently assume the form of a huge irregular body of ore, which is generally limited to a certain extent, when it assumes the form of the vein and its course again. Steep veins are generally irregular, and often divided into small branches, ramifying the rocks, uniting, however, always in a peculiar spot, again to pursue their course together in their natural manner. These veins always have a general direction, and the course of most of them is from S. W. to N. E. If their direction is from W. to E., we may suspect their true nature, at least they will not extend far. In observing these general laws, and the exceptions, we hardly can fail to discover the true course of a vein. Veins of this kind are, however, frequently disturbed by faults, which cause apparent alterations in the line of progress, but we find the true direction always again by following through the fault to where the vein sets in again. Such intersections are often found to be vexatious, but if we follow the vein through the fault, we discover the ore. In some instances, the vein is crossed under certain angles by another vein; if we know the angles of such crossings generally, we soon detect the original vein, if it has been disturbed in its true course. Faults are quite common in the veins along the Atlantic coast, and but few are observed in the western coal basin.

Plan of a mine.—When the survey has been so far completed as the extent of ground requires, it is drawn on paper, and so arranged as to show all its relations to the locality. A perfect plan of the ground is laid out, the vein traced on that surface; sections, perpendicularly and horizontally, are drawn, which show the vein in all positions. Upon these plans a system of working the mine, for its ventilation, and the hoisting of water and ore is treated.

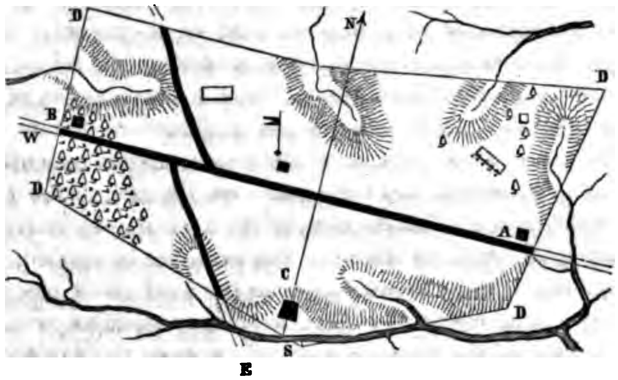
FIG. 5.



In fig. 5, a section of a vein is represented, which belongs to the plan fig. 6. This vein may be examined over the surface of the hill, and the fault A may be found in that examination; but if it is not found at or near the surface, and the lower part of the vein cannot be found because it is covered by alluvium, we are under the necessity of working the mine at random, or lose much by working it to disadvantage. In such instances a general knowledge of the character of ore deposits is of great value. If the vein sets in parallel at the top, or so far as it can be examined, we can depend upon its continuance, and may confidently commence operations at the lowest point, above the water-level of the grounds. Is the mineral deposit a mass, that is, are its walls irregular, diverging in one or the other direction, it is unsafe to attack the mass from below, for it may not reach at all to that depth, or may turn in a direction opposite to that indicated above. In this case, it is advisable to drive a level not lower down than the deposit has been examined at the surface. Is the character of a mineral vein of an irregular form, composed of pockets and small veins, such forms in which lead ores generally are found, we cannot form a correct plan of the mine, the operation is, in this case, of a hazardous nature. In such instances the best plan is to drive a level conveniently to the discharge of water, and the hauling of the ore, in the direction of the deposit. Pockets are, therefore, the most disadvantageous forms of veins, no system of working can be applied, and, on the whole, it is mere accident if a mine of small extent of this kind of veins succeeds. The parallel, or regular vein, the lode, or irregular vein, and the mass, are the most profitable forms for cheap extraction.

Fig. 6, D D D D, is a lot of ground through which a mineral vein has been traced. Its direction, with all its deviations from the straight line, is drawn on paper, and in the position as it appears in nature; all the hills, ravines, houses, forests, and fields must be marked out. The owner's name, and the names of the adjoining neighbors, and the boundaries, must be inserted in the plan; and, if possible, the deviation of the magnetic meridian from the true meridian, marked in the drawing. In this plan of the ground, the direction and thickness of the known vein is marked, in a color indicative of the color of the mineral. Is more than one vein, D F, known, these are marked also in the plan; and if a vein is present which crosses the first, it must be particularly marked. When all the veins are marked down on the plan, various sections are compiled with the assistance of the means, obtained by coal examination; these sections must be laid in certain directions, and marked accordingly. A section, as that represented in fig. 5, it is almost impossible to find by surface-digging, and for this reason a straight vein is assumed in the plan and section. When the fault of the vein is found by actual work below ground, it is subsequently marked in the plan. Various sections may thus be drawn, and the veins put into their true position and relation. In this instance, where the course of the main vein, A B, is from E. to W., and the dip from N. to S., and the hill is sloping with the dip, we naturally are inclined to start a level from the water-course below, in the shortest distance from C to the vein, particularly if a ravine cuts the hill at right angles with the vein. An arrangement of this kind would answer the purpose very well, provided no water comes down the ravine, for in that instance the level or drift will be always wet, annoy the workmen, and destroy the timber before its natural decay. A drift is, therefore, never to be in a wet place, below a ravine, or in a direction from which springs issue; it must be driven through the dryest part of the hill. If the water comes into the mine, it is better to come down in any other place than in the drift. Is the extent of the property limited to a short line along the creek, and is the drift to start from this place, it is advisable to put the mouth of the drift at the extreme eastern point, particularly if a second workable vein should cross the first, as in this instance. We cut now the level parallel with D A, and reach the end of the main vein in A. If the air is bad in the mine, which is generally the case if the work is performed during summer season, an air shaft ought to be sunk at A while the drift is progressing. If

Fig. 6.

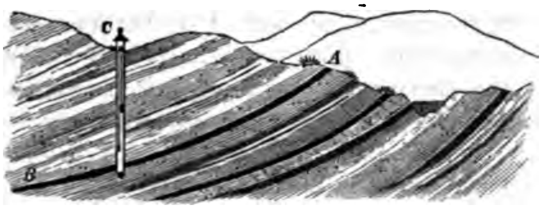


the work of the drift is carried on during winter, and the mine not very extensive, the work may be accomplished in the cold season, and the point B reached by a gallery from A in time to prevent the influence of hot weather. Either at A or at B there must be an air-shaft in all instances, of whatever kind or nature the mineral may be. It is advantageous to enter the vein at one end and have the air-shaft at the other end; this arrangement will cause circulation through the whole length of the vein A B. Is the second or cross vein, F E, also to be worked, it may be extracted from the same mouth with A B; but it cannot be driven further than that vein, for the part lying behind it cannot be ventilated by the one air-shaft, and a second at the extremity of the latter vein is required to bring fresh air into the farthest part of the vein. The vein E F may be opened by a gallery which drains the main vein from E, and also by the dead level from A. The dead level, A C, as well as the galleries driven from A to B and from E to B, must have sufficient fall in the floor so as to carry off the water conveniently, and prevent any accumulation of it in the interior, even in wet seasons.

This method of starting a mine is certainly preferable to working a similar deposit by shafts. The dead level, C A, may be at first expensive, particularly if the vein dips in opposite directions to the slope of the hill; but these expenses are soon repaid by the greater facility with which hauling, draining, and airing is accomplished. A mine may thus be worked without steam-power, to the depth of the natural drain; and if the veins are exhausted so far, a steam-engine, or water-power is required only to raise the water from the greater depth to this natural level. The ventilating of a mine is also more convenient and safe; and so far as it is above the drift, there is never any difficulty about fresh air in the mine.

Is the ground level, or but gently undulating, under which a deposit of ore is hidden, the manner of laying down a plan for operations is in principle the same as above. In this instance we cannot reach the vein by a level drift, it may be because such a drift would be too long, or its mouth fall beyond the limits of the property. We are also compelled to work the mine by shafts. If a vein, A B, fig. 7, is only a little elevated above the general water-level of the locality, and would a dead-level driven to it from a water-course lay but a small part of the vein dry, the vein can be entered at A by an inclined plane, following the inclination of the vein; or, what is preferable to that plan, a perpendicular shaft is sunk down from C, and the hoisting done by means of this shaft. The distance of the shaft from the out-crop depends on the inclination of the vein and its probable extent and direction below ground, the extent of the property above, and the means at disposal. If the vein is not well known, it is advisable not to go too far off from the out-crop, else the vein may disappear, or turn in a direction beyond our reach. From the shaft, a horizontal drift may be cut at a certain depth in the direction towards the vein in order to secure the permanency of the shaft, and in the mean time save means and time at the outset; the money, however, laid out for such drift is a dead loss. If means and time admit, it is always preferable to go with the shaft so far as to reach finally the greatest depth of the vein. The shaft may even cross the vein, and reach its lower parts by means of levels; this, however, has its disadvantages as well as levels above the crossing-point. One shaft is in all cases sufficient for hoisting and pumping; it ought to be in the centre of the property, or the centre of the vein belonging to the property, so as to make the distance of transport below ground as short as possible. Every mine requires at least one air-shaft, and for these reasons two shafts, such as A B, fig. 6, are generally placed at the opposite extremities of the vein; one shaft serves here for hoisting, the other for ventilation. This plan is very imperfect, it causes much hauling below ground; and if the one shaft is not considerably higher than the other, the ventilation is often disturbed. In these instances, it is the better plan to locate the engine and hoisting machinery on the lowest part of the property, in case the out-crop of the vein is higher than that, and the water from the pumps of the engine can be drained. Is the out-crop of the vein lower than any other part of the ground, it is advisable to lay the mouth of the shaft as high as possible, in order to secure draught through the mine. When the shaft is in the middle

FIG. 7.



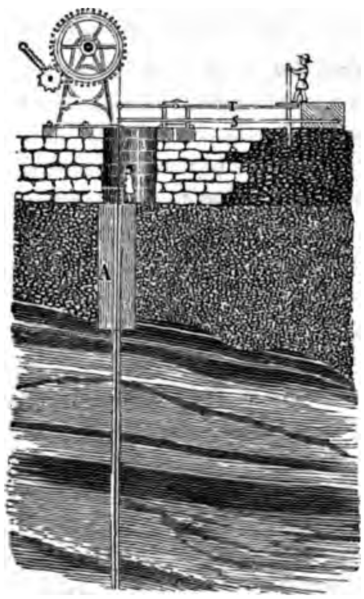
of the vein, two sloping shafts at each end of the vein are driven from below, from the galleries, in case the air is good inside, so as to admit of such an operation, which may succeed in cold weather and in oxides; but it hardly succeeds in sulphurets, and not at all in coal. In cases where the work cannot be done from below, it must be done from above, which is more expensive. It is in all instances preferable, if these air-shafts can be driven in the vein itself, instead of in the rock, or at least at the terminations of the vein, or at its out-crop. In all cases, a considerable difference in the level and height of the various outlets ought to be provided for, in order to procure the necessary draft in one of these outlets. If a vein is more or less inclined, or Is it entirely vertical, or horizontal, there is no difference in the application of these principles; drainage, air, and saving of labor below are the conditions which guide the laying down of the plans. Reasonable expenses, so far as first cost and time are concerned, must be, and are, of a secondary nature. It would be bad practice to spend means imprudently, for the object of mining is after all but a plain business; and if the capital invested does not pay interest and repay itself before the vein is exhausted, it is advisable not to engage in it.

Irregular Veins.—If, in examining the out-crop of a vein, we cannot decide of what form the deposit may be, we are compelled to work at random, without laying down a plan of operation, and may in this way injure the vein for future operations and our own interest. Of all such veins as coal veins, and mineral veins in stratified rocks which run parallel with the strata, there is little doubt of their continuing in the general direction, but veins which penetrate unstratified rock, alluvium, .conglomerate, or cross stratified rocks, are not quite safe so far as their regularity is concerned. It is, however, necessary to know very nearly the direction, inclination, extent, and thickness of the vein before we are justified in erecting machinery or concluding a plan of operation. Is the deposit thick into which we penetrate, it is advisable to follow its lower plane, in order to penetrate the mass from below in case it is found to be a mass. If the nature of the vein cannot be ascertained by any means from above, it is advisable to penetrate the ground by boring holes, such holes as are sunk for drawing salt water from a great depth. The boring of an artesian well, or a salt well, is quite a common operation, and requires but little skill and means; still there are some advantages in doing the work right, it saves means and time, and for these reasons we will furnish a description of the operation, in the manner in which it is performed most profitably.

CHAPTER II.

Boring for Minerals.—There is no difference in the system of boring for minerals, or boring for water; the kind of rock to be penetrated does not even cause any material difference to be made in the means or tools by which it is done. In the Western States, such as Virginia, Ohio, Western Pennsylvania, Western New-York, and others, this subject is well understood and well performed. Those who make a business of boring for salt water, penetrate the stratified rock of the bituminous coal formation, at the rate of $1 per foot, for a 3 inch hole; this width is in all cases sufficient for a test on a mineral vein. In the above States the hemp or manilla rope is used for boring. This is called the Chinese method, because the Chinese have practised boring in that manner since our knowledge of them. The Germans penetrate the rock by means of iron rods, of one inch square or more. These rods are screwed together in lengths of 10 or 12 feet. This mode of work causes the operation to be rather expensive, on account of the price of tools and machinery, and it is not very expeditious. The same method was followed by other European nations, and formerly in this country. In recent works of this kind, wooden rods have been used with greater advantage than iron. These rods are long slender poles of pine wood, often 30 and more feet long, mounted with iron and screwed together; they have the advantage of being light and elastic, so as to cause less concussion and consequently less repair than iron rods. Rods offer no advantage over the rope but that of longer durability, and the earth may be penetrated to a greater depth by means of them than by ropes. The latter are limited on account of strength to about 1,000 feet, while rods may be driven down to 2,000 feet and deeper. We will describe an apparatus which may be used either for hemp-rope or wire-rope, which was made originally for hoop-iron by the author, it being cheaper and served the same purpose as ropes of either kind.

Fig. 8.



At A, in fig. 8, is represented a log of oak wood, which is set perpendicularly so deep in the ground as to penetrate the loose gravel and pass a little into the rock, so as to stand firm in its place; it is well rammed by gravel, and the ground levelled so that the butt of the log is flush with the surface of the ground, or a few feet below. Through this log, which may be, according to the depth of loose ground, from 5 to 30 feet long, a vertical hole is bored by an auger of a diameter equal to that of the boring in the rock. On the top of the ground, on one side of the hole, is a windlass, whose drum is 5 feet in diameter, and the cog-wheel which drives it 6 feet; the pinion on the crank-axle is 6 inches. This windlass serves for hoisting the spindle or drill, and is of a large diameter, in order to prevent short bends in the iron which would soon make it brittle. In all cases where iron, either hoop-iron or wire-rope, is used, the diameter of the drum of the windlass must be sufficiently large to prevent a permanent bend in the iron. On the opposite side of the windlass is a lever of unequal leverage, about one-third at the side of the hole, and two-thirds at the opposite side, where it ends in a cross or broad end in case men do the work. The workmen, with one foot on a bench or platform, rest their hands on a railing and work with the other foot the long end of the lever. In this way the whole weight of the men is made use of, who work with great ease. The lift of the bore-bit is from 10 to 12 inches, which causes the men to work the treadle from 20 to 24 inches high. Below the treadle T is a spring-pole S fastened under the platform on which the men stand; the end of this spring-pole is connected by a link to the working-end of the lever, or the hoop-iron directly, and pulls the treadle down. When the bore-spindle is raised by means of the treadle, the spring-pole imparts to it a sudden return, and increases by these means the velocity of the bit, and consequently that of the stroke downwards.

The spindle is represented in fig. 9, a piece of square cast iron, or wrought iron, of from 200 to 300 lbs. weight for a hole of three inches diameter. For larger holes, of 5 or 6 inches diameter, its weight must be increased to 800 or 1000 pounds. At one end of the spindle the hoop-iron or rope is permanently fastened by screws or rivets; at the other end the bore-bit is inserted in a round hole and fastened by a flat key. The spindle may be provided at each end with a head, in the form of a cross, but these are unnecessary appendages; a simple square rod of iron, whose diagonal section is equal to the diameter of the hole, is all-sufficient for the purpose. The lengths or parts of the hoop-iron may be made as great as possible, and should be of the best fibrous charcoal iron; puddled iron, even if fibrous, soon gets brittle in the course of time and work. For a spindle of 300 lbs., hoop-iron of 2 inches by $\frac{1}{12}$ is abundantly strong, for heavier spindles it may be somewhat stronger. The ends of the hoops are fastened together by means of small rivets and drilled holes, and this riveting ought to be renewed at least every two months, because the repeated vibrations cause the iron to get brittle, which is the case at the joints more than in the run of the iron. At the upper end, where the hoop is fastened to the lever, there is a length of hoop-iron nearly equal to one length or part, at one end of which is an eye permanently fastened; this fits in a hook at the lever, and also in a hook at the drum. This loose part of the strap is fastened to it by means of pinch screws, as shown in fig. 10, by this means the hoop may be made longer and shorter, as the bottom of the bore sinks down; the letting out, of course, can be performed only while the work is stopped. If we want to let out while the treadle is in motion, which is necessary in soft rock, a screw about one foot long is provided at the end of the treadle, which may be turned while the machine is in operation. The bore-bit has been shown in fig. 9 as it is fastened to the spindle. This is a simple, flat chisel, whose edge is steeled with good cast steel, and a little rounded, so as to play always in the centre of the hole. If the chisel is too round, or pointed in

FIG. 9.

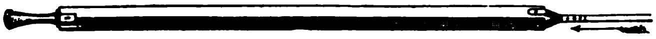
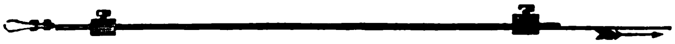


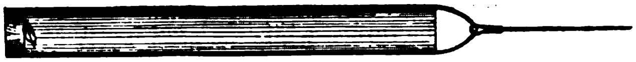
Fig. 10.



the middle, the hole is liable to get narrow in the bottom; if the edge is straight, the hole generally widens with its depth. Other forms of the bit are of little use, they merely cause trouble and loss of time. The bit must be fastened very firmly in the spindle, and the shoulder of it fit closely to it, or both are liable to get out of order. When the spindle is to be lifted from the pit, the end of the hoop is taken from the treadle and hitched to the drum, which is set in motion. The hoop must be prevented from winding over the hook's eye, or the pinch screws, for that would cause short bends in the iron and permanently injure it. The drum must be so high above the hole that the spindle may be lifted entirely above the bore-log. For these reasons the upper end of the latter is frequently found to be some feet below the surface of the ground.

The operation of boring is simple; when the hole through the bore-log is sunk, the spindle is let down, hitched to the treadle, and the latter set in motion, which labor two or three strong men can readily perform. If but ten or twelve inches lift is imparted to the bit, from 30 to 40 strokes may be made in one minute. If a good hoop-pole is appended, from 30 to 45 strokes may be made by men, and from 80 to 100 by a steam engine. The rock is thus penetrated by repeated blows, of which from 50 to 100 are sufficient to sink one inch deep in soft slate and shale; from 500 to 1000 in sandstone rock, and from 10,000 to 20,000 strokes in graywacke or gneiss. Even as many as 30,000 and 40,000 blows have been struck to penetrate one inch deep in hard graywacke. Iron pyrites are almost impenetrable, and the best plan is, if the vein is but a few inches thick, to break it by heavy strokes of a blunt steel point, directed so as to break off pieces from the mineral. When a certain depth, say one foot, or two feet, is penetrated, the debris of rock, ground into dust, and floating as fine sand in the water of the hole, must be removed, which is done by the pump; this instrument is represented in fig. 11; it is a sheet iron cylinder of from 3 to 4 feet long, and

Fig. 11.



¼ or ½ inch smaller in diameter than the diameter of the hole, so that it may pass down easily; it is provided at its bottom with a strong iron ring riveted firmly, and soldered to the sheet iron;

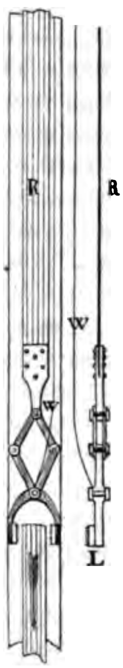
upon this ring is fitted a valve, which may be a poppet valve, or a ball, or what is equally as good as any, a trap valve formed of a piece of sole leather or strong India-rubber, provided with a piece of metal to make it heavy and shut close. Metal valves do not shut well, for often coarse sand gets into the pump, which does not admit of a hard valve to shut, while a light valve of soft matter will press the sand out, or at least close sufficiently tight to prevent the mud from flowing out. This bucket is gently let down upon the bottom of the well by means of a small rope, a wire-rope, or a hoop-iron tape; it is then rapidly moved up and down a few times by hand, and raised. This latter operation is best performed by a small windlass, erected purposely for the pump. The strong windlass is too heavy and slow for this operation. When the pumping has been repeated two or three times, we may suppose at least all the heavy sand is removed from the bottom of the well. Pumping ought to be performed after the water has been for a while at rest, early in the morning or after meal times. This operation is very simple and effectual. The pump in being raised rapidly from the bottom of the well causes a strong current of water to pass vertically down, this stirs all the heavy sand in the bottom, and even pieces of iron and steel which may accidentally fall into the well, and brings them into the pump. Many other devices have been proposed for this purpose, but we know of nothing superior to this simple machine.

Boring by steam.—Where a steam engine is at command, as is generally the case at salt wells, the operation may be performed with ease and cheaply. Is a water-wheel or a mill at the place where a hole is to be sunk, the expenses are very small, one man attending the whole operation. In most cases it does not make much difference where the hole is driven down, if not too far off from the out-crop, so as not to miss the ore deposit. If the extent of a mass or vein is known, and we want merely to know the depth from a certain point, in order to calculate the expenses of a shaft before we sink it, it may be profitable to erect a steam engine for boring, in case the depth is considerable. Horses or mules may be also employed at a common horse-whim to do the work; this, however, is not much cheaper than manual labor, but the work may be done faster. In case a steam engine, water-wheel, or horse-power is used, a shaft with cams or tappets must be provided, which latter press upon the treadle instead of the feet of men. If in this arrangement the shaft with tappets can be so arranged as to be moved farther off, or closer to the treadle, it is recommended; for if changing stratified rock is met with, different heights of stroke or change of lift is required; soft rock or slate cannot bear as strong blows as hard rock. In this case the spring-pole must be strong enough to balance the whole weight of spindle, and rope or iron belt, so as to keep it suspended when at rest. The large drum for winding up the rope, may serve as an axle for tappets; the latter are then fastened to the large cog-wheel and lift the treadle directly, or what is the same, the end of the rope or iron belt. The crank-shaft on which the handles are, serves in this case as a driving shaft, driven by pulleys and belt from the engine, the water-wheel or horse-power.

Turning the spindle, or bit, is a necessary operation which is much favored by a hemp-rope, not so much by a wire-rope, not at all by hoop-iron, or by rigid bars of iron or wood. In striking the bottom of the well by the sharp chisel, it is to turn around the axis of the spindle, or its own axis, in order to cut a round hole; the more rapid this operation is performed, the more correct is the work, and the faster it proceeds. The hemp-rope, in lifting the spindle, is stretched, and endeavors to untwist, setting the spindle in a rotary motion, in which it continues until its return to the bottom of the well. At the head of the spindle there is a loose eye, or swivel, in which the rope is fastened: the rope will return, when slackened, and assume its twist again. This operation, however destructive to the rope, performs the rotary motion of the bit more perfectly than any other means. The rigid-rod, and the hoop-iron or wire-rope, must be turned by hand, if no machinery is expressly prepared for the purpose. If turned by hand, which is done by means of a cross-handle above the bore-log by a small boy, it ought to be done rapidly; each stroke ought to have more or less than a whole revolution. If this operation is not properly attended to, the bit is very apt to cut rifles or flutes, particularly in stratified rock, which are very troublesome in the progress of the work.

Accidents.—It may happen that the belt, rope, or the rod breaks, or the bit or spindle is injured, and leaves parts of steel and iron in the hole. If the latter is the case, and the pieces broken off are not too large, the most expeditious plan is, to take a dull hard bit and pound the iron into such small pieces as may be removed by the pump. Is the belt or rod broken, the operation is is not difficult, but in the latter case tedious. The hoop-iron, or a hemp or wire-rope is easily drawn up, which is most conveniently done by the following machine. In fig. 12 is represented a pair of tongs, which are fastened to the main rope R, which is slackened in letting down the tongs. W is a single wire, or a small hemp-rope, such as a bed-cord, or the pump-rope. When the tongs are so far down as to be below the broken end of the rope, the wire W is pulled so as to open the tongs, after which the belt R is turned round its axis. The lips L of the tongs, forming a basket, sweep now the circumference of the hole, and draw the broken rod into their grasp; when such indications are perceived at the upper end where the workman is turning the belt R, the wire W is suddenly slacked, and the sharp steel lips will bite the iron or hemp; the whole is now lifted by the windlass, and the broken ends mended. With a wrought-iron spindle, hardly any thing can happen; a cast-iron spindle may break, but if made of a square form, there is so much room on the four flat sides as to admit two sharp-pointed bits of the tongs, which may fasten in it sufficiently so as to lift it. More vexatious than such breaks is the crumbling of rocks, particularly if these rocks are hard or tough. If the spindle has a little space at its upper end, and a piece of rock falls down from a higher place and wedges in between the spindle and the walls of the well, it causes often long delay and much labor to remove such small stones. Is the treadle moved by men, such impediments are generally observed before the rope breaks, and may be made less disturbing when attended to in proper time; but if a steam engine or other power is at work, it will tear the rope or rod, and cause the spindle to be tightly wedged. In order to prevent the breaking of the rope, that part of the lifter where the rod is suspended must be made so weak, that, when the cam lifts it, and it is heavier than the weight of rope, spindle, and bit, it will break and prevent by its rupture the breaking of the rope. Is the latter not injured, there is generally not much difficulty in getting the spindle out. At the top of the bore-hole must be always a certain mark, which indicates exactly the depth of the well by the length of the rope; if

Fig. 12.



the spindle is in any way raised above the bottom, we may know it by this mark, or by the position of the treadle. In this case, gentle up and down motions at the rope will generally loosen the spindle so as to make it play; its going down to the bottom, however, ought to be prevented, for which reasons the end of the rope is laid on the windlass, and the rope so far stretched as to prevent its sinking to the bottom. By means of the treadle or by hand, the apparatus is now kept in motion and gently raised by the windlass. If these means will not succeed, force at the windlass is tried, but never beyond the strength of the rope so as to break it. If this also fails to lift the spindle, an iron rod, with a blunt end, which cannot penetrate between the spindle and the walls of the hole, is let down by means of the pump-rope, and gentle blows are imparted on the head of the spindle; this will either start the spindle, or will crush the pebbles which hold it. Is the rope or rod broken, these operations must be performed with more caution, so as to prevent forcible lifting; for when the tongs have hold of the broken end of the belt, that is never so firm as the rope or belt itself.

Cementing.—Most of the accidents are caused by loose stones, gravel or pebbles, crystals or pieces of slate, from cavities above. Most of the rocks contain caves, or nests of crystalline loose matter, which is thrown down by the motion of the water and the vibrations of the boring instruments. In these cases, pipes of sheet-iron, of copper, or of other metals, have been inserted in such places; which operation, however, is expensive, tedious, and not quite safe; much ingenuity has been expended on inserting such pipes. In all cases of boring, the mouth of the well, or upper part, ought to be well secured by the bore-log; it should reach down into the solid rock, and prevent any dropping of gravel from above. When, in the course of the descent, cavities are penetrated which prove to be filled with loose matter, threatening to obstruct the progress of the operation, the best plan is to cut through such a cavern, if possible, and reach the solid rock again. If this cannot be accomplished, the chisel is driven down as far as possible, and the cavity filled by cement, which is closely rammed in by a plunger. The cement for this purpose is mortar cement, also called Roman cement, which is made of impure limestone, such as is found in the coal regions and marl beds, in the form of lumps imbedded in marl, clay, or shale. This kind of limestone, when burned, does not slack; it must be ground fine, and is then mixed with water to a stiff mortar. If no such impure limestone can be obtained, common lime is mixed with burnt and finely-ground iron ore, burnt marl, or burnt ferruginous shale, pumice-stone, or any kind of volcanic porous rock. The whole, lime and admixture, of which latter about 40 per cent. of the lime is used, is ground together and mixed with water so as to form a stiff mortar. Cement mortar will harden in the course of a few days under water; but it is advisable to make a trial of it before it is put down into the well. This mortar is filled in canvas or muslin bags, of such a size as to sink gently down to the bottom of the well. A number of filled bags is let down, and then the plunger,—which may be the spindle,—is pressed upon them to break the bags, and drive the mortar into the cavity. This is gradually filled entirely with mortar, and then left at rest for some days. Part of the mortar is, in the mean time, immersed in water, above ground, in order to observe its progress of hardening. When the mortar is hardened below, it is penetrated by the bit, and a round hole bored through it, which forms now a pipe of cement, which will effectually prevent sand or gravel from running down and cause disturbances in the operations. The expenses of sinking a hole of 3 inches, range from $1 to $5 per foot deep, according to the rock and machinery.

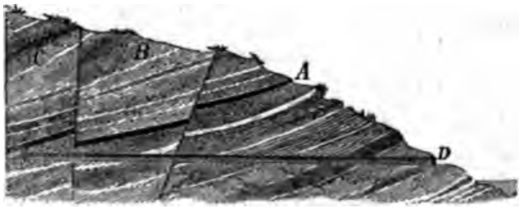
Saving of bore-meal.—In all cases of sinking a well or a bore-hole, the progress of the work should be recorded in a journal from day to day; and each day, or at each pumping, a part of the bore-meal, or the coarsest debris, saved for future examination. The latter operation is simple and causes no loss of time. When the pump is raised, the contents of it are cast into a fine wire sieve, or into a bag of fine wire gauze, which is made to contain all the contents of the pump. The water and the fine parts of rocky matter will pass through the meshes of the sieve and float off, while the coarser parts remain. A part of the sediment is saved in a paper, or in a small box, and it is marked with the time and depth, when and where obtained, for future reference. These evidences, when put together, form the elements of a section of the rock strata penetrated by the well, in that particular spot, and are suitable objects for publication. Any geologist can form, by these means, a profile of the rock, or general formation. Many hundreds of artesian wells are now sunk, and have been sunk in times past in our country; these would furnish means for obtaining a correct insight in the geology of those places where the operations are performed. For the want of such records, the information arising from the labor of boring, at a particular spot, is lost to the community and the science of geology.

Any size of hole will answer the purpose of the miner, and if 2 inches in diameter could be sunk, it would be sufficiently wide; but this cannot be done; the form of the tools, pump, and rope require at least 2·5 inches. All complicated tools, such as cross-chisels, rasps for widening, and similar instruments, are to be avöided. They are expensive, both in first cost, repair, and cause loss of time. The simple flat chisel will form a perfectly round hole; when attended to in turning the rope, it will make the hole wide enough all the way down; if frequently changed and sharpened, it works easy and fast. A chisel and a good pump, a safe rope, and good tongs, are all the implements requisite for sinking a hole of 2,000 feet deep.

CHAPTER III.

Nature of a vein.—By means of exterior examinations, and if necessary by the assistance of boring, we may thus form a correct impression of the form, extent, and quality of the mineral, and by that means we obtain the elements for a plan of extracting it. We may to some extent conclude on these relations by general principles; namely, veins running parallel with the rock-strata must be continuous; this, however, is not always the fact, for in these veins there may be extensive faults, which make a different plan of operation necessary. If in fig. 13, where a horizontal vein is represented, the fault B happens to be within the field of our operation, it would be improper to drive a level into

Fig. 13.



the vein at A, for that level can reach but the one part of the vein. It is necessary here to drive under A and reach B, so as to drain and work it by the same level. If C is lower than A, it is required to drive in at D, in order to drain the whole of the vein from A to C. These cases happen in coal veins; and if our western coal field is not much disturbed by faults, they are there, and have caused expenses and delay in mining. Geology furnishes general principles on the form of mineral deposits, such as, veins of the primitive rocks are the results of clefts filled by minerals. This, if admitted to be true, excludes not the examination of a vein, for such clefts are not regular. We find these veins progressing in a general direction; but they are frequently so far disturbed by local influences, that a working plan based upon the general direction of a vein, would not reach the local part of it. Masses and lodes are still more uncertain than veins, and for these reasous require a more thorough examination than veins. Pockets and nests, nodules and their ramifications, are frequently very irregularly distributed; these can hardly be examined by either boring or surface exposure; we must investigate the general direction of such deposits, aud endeavor to reach them by the best means and least expense. All the veins and masses which do not run parallel with the strata of rock it may be assumed are filled rents. With regard to the manner in which the rent has been filled, different forces have been acting, and the nature of the deposit assumes accordingly a different aspect. Lodes which are wide at the top, with smooth walls of the same material on both sides, we are justified in assuming to be wedge-shaped, thinning gradually in the convergence of their walls. The mineral and foreign matter having been introduced from the surface of the ground, have been carried along by a current of water. Are the walls of a vein rough, and do they show signs of having been under the influence of a higher heat than the surrounding rock generally, we are warranted to conclude that the rent has been caused and filled by an expansive force from below. In the latter case we expect an increase of mineral with the depth, and in the first a decrease of it. Since the bulk of mineral veins is composed of sulphurets, and these are volatile, we conclude that all small fissures, pockets and cavities, which are filled by sulphurets, have been so filled by the vapors of these metals deposited in the cavities. The lead ores of Missouri and Arkansas owe their origin to this cause, also the gold ores of the southern States, and in fact most of the pyriteous ores of the eastern States. These are, therefore, valuable deposits; their quantity must increase with the depth, and we can safely depend upon success in our operations, if we follow the veins to the greatest practicable depth. The igneous origin of a vein is in all cases the most promising, because its dimension increases with the depth.

When we thus assert that certain principles have been active in forming mineral veins, it must follow that when a vein is formed under a certain law it can contain only certain kinds of minerals. Gold, particularly sulphuret of gold, is volatile; the same as all other metals and sulphurets, it is soluble in alkalies, but precipitated in the presence of any metallic oxide, or an acid like silex, or by heat from a fluid solution. If its sulphuret is soluble in a sulphuret of lime or magnesia, its metal cannot be found in a limestone deposit, because water has removed it thence and deposited it upon some silicious rock. Sulphuret of lead is not soluble in lime or any alkali, and slightly soluble in acids, it is therefore precipitated more abundantly in lime than in silicious rock. Sulphuret of silver, and the sulphurets of the precious metals generally, behave similar to gold, and this may be the reason why we do not find them in or near limestone rocks. The protoxides of iron show more affinity for silicious matter or acids, than for lime or alkalies, and this may be the reason why we do not find them in limestone. The magnetic oxide and peroxide, as well as the sulphurets, have as little affinity for lime as for silex, and consequently we find them universally distributed. These chemical principles may in some measure guide our conclusions in respect to localities and the minerals therein. These affinities are evidently active in the distribution of minerals. We hardly find any gold but in the vicinity of quartz; and, under similar circumstances, the largest quantity of it near the largest quantity of silex. In veins of galena which contain silver, we find always most of the silver exterior to the vein, near its walls, and particularly in the fork of a vein where it branches out into smaller veins; showing evidently that the silver has more affinity for the rock than for the lead. The same principle has been acting in the distribution of zinc, antimony, and particularly tin.

Theory of the formation of mineral deposits.—The sulphurets of gold, platina, tin, antimony and arsenic, are subject to the same laws of affinity, that is, are soluble in alkalies, and when exposed to a certain degree of heat in the presence of an acid, such as silex, the sulphur is dissipated, and gold or platina are reduced to their metallic state, and disseminated through the rock. Tin, antimony and arsenic, having a great affinity for oxygen, become oxidized, and the first concentrates, in virtue of its great cohesion, into crystals of oxide of tin, which are heavy and cannot be carried far from their origin; antimony and arsenic are more soluble, and may be carried to a certain distance, precipitating on matter to which they have most affinity. The alkalies which originally held these sulphurets in solution are washed away, and combine with acids, being deposited still further off from that place where the sulphur was dissipated than the lightest of the oxides of the heavy metals. On this theory of the formation of mineral deposits, which supposes all the heavy metals to have been originally in combination with sulphur, we must find gold, platinum, and the platinum metals, near the oldest rocks, and rocks of igneous origin, in a metallic state; tin, antimony and arsenic, near these sources in an oxidized state; iron everywhere, because in the presence of oxygen or water its sulphur was driven off, the iron being oxidized and condensing near its source into solid crystals, or amorphous masses, which latter floated off, to be deposited in places where affinity held it. Lead, having the greatest affinity for sulphur, would dissipate with it, and float to some alkaline deposit where it is attracted. Similar results, caused by the same force, may be traced with almost all mineral matter. If we suppose that in the primitive condition of the earth, less oxygen was combined with matter, and that a mixture of all the elements existed, with little or no oxygen, we find a sure guide for tracing the origin of the deposits. This theory is strongly supported and corroborated by the successive oxidation of the rocks generally. Volcanic eruptions, which may be compared to the first operations on the thin crust of the earth, emit sulphurous vapors, chlorides, and volatile metals, and deposit oxides. The silicates thrown off by these forces are in a low degree of oxidation; this is, therefore, an evidence of a want of oxygen in the deep. Granite is in a state of higher oxidation, but not the highest. The stratified rocks contain more and higher oxidized matter than granite; the coal formations more oxygen than transition rocks, and the tertiary rocks more than either of the foregoing, hydrates making their appearance among them, which is a certain indication of a high state of oxidation. In the most recent deposits we find hardly any matter which is not oxidized to the highest degree of its natural capacity for oxygen.

As a theory, accounting for the distribution of minerals over the globe, we consider the foregoing more satisfactory than that based upon the facts eliminated by geology. It at once explains the cause, and accounts for the locality of a deposit. We find by its assistance, why gold, tin, antimony, and arsenic, cannot be found far off from granite, and must be in or near silicious rock, no matter what its age and history may be. We find also, that more silver must be in the galena of silicious deposits, than in the galena of alkaline rock. It accounts for those deposits which are the result of infiltration, for masses, and stratified veins. Injections from below, lifted by heat from the deep, are in their primitive condition and are not subject to the above rule; they are recent evaporizations or injections in mass, condensed by the cold strata, or massive rock which they penetrate.

In taking all these elements together, we obtain the means for forming the plan of working a mine. It requires different means to work an alluvial mass or vein, a mass in secondary rock, infiltrated or injected veins. The object is in all cases to obtain the minerals at the least expense. If we commence the working of a vein at a higher elevation than its lowest point, we may incur great additional expenses in driving for the lower parts of it by subsequent dead work, the labor spent on the first being entirely lost. If we attack a mass at its top instead of at its bottom, we may permanently injure the mine. Before a pick is used in the opening of the mine, all advantages and disadvantages must be well considered; the nature and value of the mineral must be known, the extent and thickness must have been investigated; its lowest and its highest points ascertained, and the probability of the origin of the deposit must form an item in determining the working plan. When all these facts have been laid down in a well drawn plan on paper, the disposition of shafts, levels, galleries, drainage, ventilation, and hoisting is provided for, and the manner of working it is decided; the expenses of the erection of machinery, and the dead work are calculated, with the cost of digging the ore and hoisting it. The value of the minerals, and the total amount which probably may be raised in the course of time, furnish the credit to the above account of expenses and shows the profit or loss which a mine may make in a certain time, or up to the time of its exhaustion.

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CHAPTER IV.

Working of a Mine.—We shall not allude to the tools and instruments used in mining, nor can we extend our remarks to blasting; we assume that these subjects are generally known. When a vein is so near the surface of the ground as not to have sufficient cover for underground work, we resort to open workings. The superincumbent ground is stripped off and removed, the mineral exposed and cleaned, and then removed. This operation is very generally performed with iron-ore deposits, and in some instances in coal-beds; it is simple, and requires no particular knowledge of the principles involved in mining. Any sagacious laborer may be a good miner in these cases. Open workings are, generally speaking, expensive, because they require a great body of foreign matter to be moved by physical labor, the application of machinery being inexpedient. If, by any possible means, such open work can be avoided, it will be found advantageous. It is cheaper to extract the same mineral by an underground mine than by open diggings. The latter are, besides the disadvantages mentioned above, exposed to all the changes of weather, the heat of the sun, frost and rain; and as the amount of work done constitutes the price of labor, the operatives in a mine cannot suffer by these changes; all the disadvantages add to the cost of the mineral, and cause its price to be higher than it probably would be if extracted by means of underground work. In many instances such work cannot be avoided. Where the ore is covered by loose ground, it would be unsafe to form a roof of it; at least, it would cost much labor and timber to prepare a roof. Where the out-crop of a vein of ore is only used, as is frequently the case in the coal regions, in which the decomposed carbonates form the objects of extraction, and where the argillaceous carbonates of the interior vein are neglected, it is impracticable to form underground workings, and if these ores do not pay for stripping, they are of no value. For particular kinds of minerals open workings are chiefly resorted to; we shall allude to these in their particular places.

Subterranean Workings.—We may divide these into two classes, that is, into veins and into masses. When a vein is horizontal, or nearly so, a level drift is driven through it, in case the vein dips towards the mouth of the pit. If this is not the case, it may be found preferable to sink a shaft at the lowest accessible point of the vein, and commence here the driving of a level for drainage and carriage. If the vein is so located that neither is expedient, we commence by driving a level below the out-crop of the vein, so as to secure the drainage from the lowest point accessible, as is represented in fig. 13. Considerations of economy decide here either the one or the other manner of working. Is a level expensive, and the amount of mineral drained by it comparatively small, it may be found cheaper to drain by means of a steam engine, and go to a greater depth with the shaft than a level could reach. Still, if a vein is so far elevated above the water-level of the country, a water-drain, which receives the waters from above it, is a powerful auxiliary to the steam engine, it takes away much work from the latter. Expediency and the expense, however, decide the question in these cases. If a coal-vein of a few acres in extent requires a long level to reach its lowest point, and if that can be done by means of a shallow shaft, it will be found cheaper to work the mine by a shaft. If the vein extends below the water-courses, and fuel is cheap, and it is the object to take out the whole of the vein, it may be found the more profitable plan to work the mine entirely by means of a shaft. Where the amount of water received by infiltration or otherwise, is great in a mine, it is in all cases, if practicable, advisable to excavate a drift for drainage. The considerations are here, the cost of the steam engine, cost of pumps, repair and attendance; if these expenses are calculated on one ton of ore, obtained from that part of the vein which is drained by the engine, compared to the cost of one ton above the draining level, so far as it lays the part of the vein above it dry, we thus obtain a comparison of both systems of mining. Are the first expenses of driving the level, and the interest on investment for the time it is not repaid by the mineral, when divided in the tons of ore taken out above it, greater than the cost of the steam-engine, shaft, fuel, repair, engineer, and interest, divided into the whole amount of minerals drained by it, then the engine is preferable to the drift. In most cases where the ore is above the general water-level, the drainage of the mine is found to be cheaper by the level than by the engine. Is the deposit below the level of the water-courses, there is no choice but to drain by the steam engine, or by means of a water-wheel.

If the question about drift or shaft is decided, then either the one or the other is set to work at. In most cases, the drift is made to serve for both draining and hauling; it is, therefore, lowest at its mouth and ascends gradually. One foot fall in 100 feet length is generally considered sufficient for carrying off the waters in a small mine. The size of a drain depends on the quantity of the water, but as a general rule, 24 inches wide by 8 inches deep forms a channel for a large quantity of water. The size of the drift, thus opened in the side of a mountain, depends on the quantity of mineral which is to be removed from the mine. When a coal or ore vein is to furnish a certain number of tons in a limited time, the drift must have a size sufficient to admit of the carrying off the mineral. When an accumulation of pockets, or small irregular veins, are the objects of mining, it is hardly advisable to spend much in opening drifts, unless it be that a large field of such small veins is to be penetrated which affords minerals for many years to come, and finally pays the expenses of making a large drift. In all cases where minerals are extracted which are not worth much expense, and are abundantly present, such as coal, alum-stone, iron-ore, and others, it is necessary to open drifts sufficiently wide and high to admit a horse and railroad track: 7 or 8 feet high by 5 feet wide in the bottom, is sufficient for such purposes. When the minerals are in limited quantity, it is imprudent to spend much in dead work. In such cases the ore is hauled in wheelbarrows or hand-carts, and the drifts are not frequently more than 5 feet high by 7 feet wide. Is the drift cut into the mineral itself, it must be made so long as to afford ample room for extracting a certain quantity of minerals in a certain time. Is the drift in the dead rock, it is always driven directly to the mineral vein, and from that point galleries are cut through the vein itself.

Galleries are level drifts in the mineral vein itself; they are pierced in the mineral on the same principle as a drift for hauling and draining, but not so much attention is paid to the form of the vault. Is the mineral vein sufficiently strong, not more than the mineral is taken out; in all cases, however, it must be wide enough to afford room for a workman, which requires, in most instances, at least 2 feet wide. Is the vein not as thick as that, some of the dead rock on either side, or on one side, of the vein is removed. Galleries are, therefore, counted dead work, because in very few instances the ore extracted pays for the work performed. In cases even where the ore vein is thick, and galleries may be driven in the vein without removing any of the dead rock, the work is never done so cheaply as when the mine is sufficiently extended. Water, bad air, want of room, and want of undermining, are causes which retard the progress of the work and increase the cost of the minerals. Galleries are driven so far as to afford ample room for a number of miners to work to advantage; and as one miner can dig but a certain amount of ore in a certain time, it follows that, according to the quantity of mineral which is to be extracted, the galleries must be extended. In most cases, the extent of the galleries is determined by the location of the air-shaft, for these galleries are the channels for conducting bad air to the air-shaft, and admit fresh air from the mouth of the drift. In all instances, these excavations form the connection between the entrance of the fresh air and the exit of the foul air. A mine cannot be worked to advantage until all the dead work is performed, that is, until drift, galleries and air-shaft are in good order. The price of the mineral cannot be at the lowest mark until all the preparatory work is done. The quantity of the mineral extracted depends on the extent of the mine, and cannot be large so long as ample room is not obtained for a sufficient number of workmen.

Shafts.—Is a stratum of minerals so located as to make its extraction by a drift impracticable, we are under the necessity of reaching it by shafts. This is always the case when the mineral is below the water-level of the country, or when localities do not admit of levels. In these instances, we commence two shafts at once, either at the extremities of the deposit, the extremities of the ground at our disposal, or at such a distance as will secure a sufficient circulation of fresh air throughout the mine. In most cases, however,one shaft—that for extraction and drainage—is located at the lowest point of the mineral, and, if possible, in the lowest part of the surface above ground; the other, or air-shaft, is then at the highest part of the vein and the highest parts of the ground. If the latter cannot be accomplished, the first is put in the most advantageous place, and the air-shaft located where it will do the most benefit below ground; the circulation or motion of air is then accomplished by artificial means.

In all cases the pit for hoisting and drainage must be sunk to the lowest part of the mineral vein, and if that cannot be reached by a vertical shaft, it is done by an inclined shaft, or a descending drift. The air-shaft must be in all cases vertical, so far as it is above the mineral. Inclined shafts afford no advantages in the abstract, but localities may favor their construction; they always cause a longer line, and consequently the removal of more dead matter than a perpendicular shaft; the pipes to the pumps are longer in the first than in the latter, and the support of the pump-rods is a serious objection to the inclined shaft. However, localities always decide this question; the presence of a motive-power in a certain spot, and improvements above ground, over the mineral below, may cause reflections which terminate in the preference of the inclined shaft. In all instances, we should avoid cutting shafts or drifts of a permanent nature into the mineral, for such may cause danger to the mine and the workmen: the latter cannot work near such excavations, because a certain amount of mineral must be around a shaft or a drift in order to secure their permanency. The size of shafts depends, as well as that of the drifts, on the quantity of the mineral to be removed in a certain time; but as these excavations serve in the mean time for hauling, draining, and ventilation, the latter must be considered in determining the size of shafts, as well as drifts.

Timbering.—Preparatory works are always intended to be permanent, at least to last as long as the mineral in the mine; they therefore must be durable, safe, and convenient. In most cases, all these requisites are supplied by timber, which increases the strength of the structures by supporting the loose and brittle rocks. In many instances, solid masonry is erected to secure the safety of a mine. Wood for timber must be of the most durable kind—locust, white-oak, red-pine—in fact, such wood as endures below the soil will be found durable in a mine. Localities determine what kind of wood is most durable. In fig. 14 is represented the manner in which a drift is commonly timbered, in case the floor is hard rock, and the lower extremities of the uprights cannot sink into it. The drain in the middle of the floor is laid low enough, so that the water which comes down between the timbers and planking finds easy access to it, and keeps the pavement of the drift perfectly dry. If the rock is soft, such as shale, slate or clay, a frame is constructed, as represented in fig. 15, the sill of which rests upon the floor, and the drain is cut below the sill so as not to obstruct the discharge of the waters. On these sills the rails for a tram-road are laid upon which the

Fig. 14.

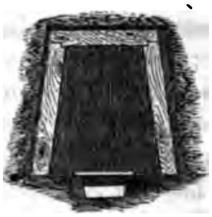
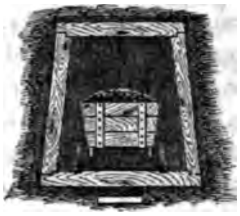


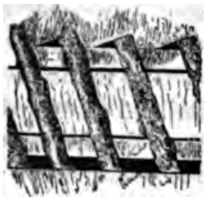
Fig. 15.



cars, loaded with minerals, are moved. Is the ground very soft, such as the entrance to a mine through soft soil or gravel, a layer of strong planks is laid, and forms the basis for the timbers. Facing-boards or planks are frequently omitted, where they are expensive, and timber is abundant. The frames are then put close together, so as to support all the loose rocks which may happen to threaten falling down. The latter plan may be applicable and advantageous in more cases than it is applied to at present. In this country labor is high and material abundant; and if we consider the high value of good plank, the short durability of slabs, and the solidity of frames, the advantages are decidedly in favor of frames. Facing-boards may be advantageously replaced by split-rails; but when we consider the time spent in making the rails, the greater amount of digging to be done in order to make room for them or planks, and also, the great facility with which frames may be put in their places, there is little doubt but that a succession of frames is the cheapest, certainly it is the most durable and convenient mode of timbering. In some instances, particularly where timber is expensive, or much exposed to decay, as is the case at the mouth of a drift, stone-walls are erected and arched over, or covered by timber. This mode of securing a drift ought to be resorted to in all cases where a great deal of surface water has access to the mine, which is experienced when the mouth of the drift falls into a ravine, or a wet place in a hill-side. In the interior of the mine, in the solid rock, not much timber is generally needed, unless it be that the rock is shivered or friable. Ore-deposits, coal-veins, and limestone-rock never form a safe roof, and it requires much timber to secure excavations in such material so as to protect the miners against being crushed. It is for these reasons, in most cases, more profitable to drive the preparatory work in dead rock, which is sufficiently strong to secure the entrance to the mine at all times, no matter what may happen to the interior of it. If a shaft or a drift should break down, the lives of the persons inside are endangered, and the mine itself may suffer serious damages.

When the rock is not uniformly brittle, and only some places in a mine are exposed to injury by dropping rocks, these are either secured by single props cut into the side-walls, or a prop and a cap to it, which latter is sunk at one end into the rock. Is the rock stratified, and nearly horizontal, as is the case in most of the Western bituminous coal-mines—and are the walls safe, but the roof shivered or slaty—holes are cut on each side on the top of the side-walls close to the roof, and timbers inserted, which are driven slanting so as to force them in tightly, as is represented in fig. 16, which shows this arrangement in a horizontal position. By these means an extremely strong roof may be formed, when the walls are safe so as to carry the roof.

Fig. 16.



When veins are vertical, or considerably steep, so that drift and gallery are the same, the timbering is performed on different principles than in the above cases. In all instances, however, the entrance to the mine must be carried out so far to the exterior of the hill that snow storms, or slips of rock or ground cannot cover the mouth of the pit. The entrance is lined with timber, in the usual manner, or walled by means of stones. Is the vein nearly vertical, the excavation forming the drift is cut out higher than a common drift; if only 8 feet high is required, the material is taken out to the height of at least 12 feet, or higher. The timber is then put in as represented in fig. 17. At the lower end it rests in a continuous channel cut in the rock. The timber is put closely together to make the strength of the roof as great as possible. Upon these timbers the rubbish of the vein is deposited, which holds them down and serves, in the mean time, as a floor for future operations. The same mode of timbering is practised in galleries, and in fact in all cases where the nature of the excavations admit of it, because it is cheap and safe. These timbers ought to be as nearly horizontal as possible, and in many instances they are laid quite horizontal, as is represented in fig.

18; or they are laid upon a continuous channel cut in the rock at both sides. Neither one nor the other of these methods is as safe as that represented in fig. 17, for in all cases the rock may give way. In such an occurrence, the first method affords more safety than the latter.

FIG. 17.

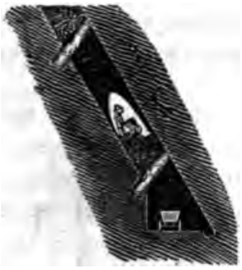
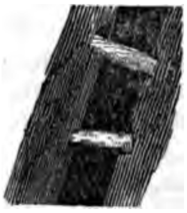
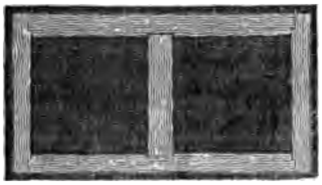


FIG. 18.



The timbering of shafts varies in form, from that of level or inclined drifts and that of galleries, but not in principle. In all cases the timber is calculated to resist the pressure of loose ground and loose stones; where the rock is solid no timber is needed. Shafts supported with timber are usually square or rectangular, and but seldom round or polygons. The spars or frames are, in this case as well as in drifts, often laid at distances one above the other, and the spaces covered on the exterior of the frames with planks, slabs, or split-rails, as facings. We find also as frequently that the frames are put close together so as to form a contiguous strong bracing of timber. Which mode of timbering is preferable depends much on the locality, but we should suppose that in most instances the close frames are the cheapest, and in all cases the strongest. When the frames are provided with face-boards, they are, generally, simply square or oblong frames fastened by wedges and iron spikes or wooden pins to the planks, as is represented in fig. 19. Is the shaft designed for hoisting only a small quantity of minerals, it is made square, and one platform is in such cases sufficient. When the amount of minerals to be hoisted is large, a double shaft, such as represented, is necessary to afford the means of hoisting. When the mine is extensive and requires strong pumps, a third apartment is provided for them to work in. This division may be either in the middle between the two hoisting shafts, or at one end of the ob-

FIG 19.



long section. In fig. 20, we have represented it as being in the middle. This arrangement affords more safety to the frame, and causes the whole of the timbering to be more substantial. The pump-shaft serves in the mean time for the descent and ascent of the workmen. Where the rock is solid no timber is used; that required for fastening the pumps and ladders, is cut into the rock and firmly wedged. In all instances, however, some means should be provided for the platforms which pass up and down to slide on; if this is on one side of the square shaft it is sufficient. In fig. 21 is a double shaft in a vertical section, represented as it descends into the coal strata at the Ohio river, but is still above the water mark of that stream. The strata are nearly horizontal and belong to Muskingum county, Ohio. A is iron ore, hydrated oxide of iron in nodules imbedded in clay, 4 feet thick; B a stratum of coarse sandstone 10 feet thick. C limestone 4 feet; D coal 1 foot; E shale 80 feet, F iron ore 1 foot, G coal 2·5 foot, H sandstone 40 feet, limestone below this; I iron ore 2 feet, K sandstone and shale 30 feet, L iron ore 1·5 foot, and from there to the river sandstone. This section, which is taken at the Licking river, furnishes a good picture of the lower strata of the coal series in the Western States.

FIG. 20.

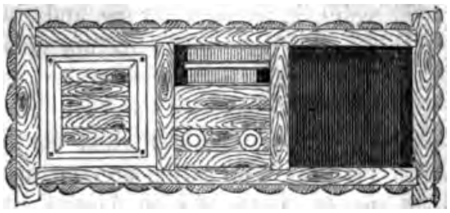
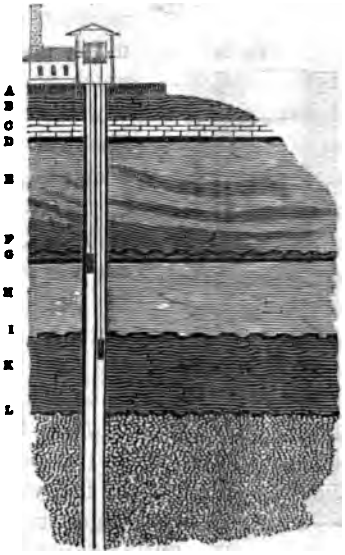


FIG. 21.



When shafts are sunk through very loose and brittle rock, and the amount of water discharged from the strata is considerable, the supporting of a shaft by timber is expensive, and not durable. In such cases it requires uncommonly strong timber, particularly when the shaft is wide, and the strata inclining or nearly perpendicular. In the latter case recourse is often had to close timbers—these are held by strong uprights and braced. In fig. 22 this mode of timbering is represented. It serves a good purpose in a shaft where two sides are perfectly safe. For inclined shafts in slaty rock, or in coal veins, it forms a strong and durable timbering. Where timber cannot be applied, which is the case in loose gravel or sand, or clay, we are compelled to wall the shaft either by means of good hard stones, or hard burnt bricks. The latter are in many cases preferable to the former, because in laying them with good cement, a waterproof wall may be erected which is in many instances of great service. When but short distances of loose gravel or loose rock are met with in the sinking of a shaft, and wood is not sufficiently secure, it is the better plan to line such places by means of cast-iron plates. The latter is a particularly good mode of securing the walls, where much water rushes from a cavity or springs, which would soon cause the decay of timber. Cast-iron plates firmly screwed together, and cemented, may be made to prevent the entrance of the water, or at least prevent its cutting the rock by being gathered into a certain part of the cast-iron lining, and from thence conducted in pipes to the place of discharge. Where water is in so great abundance as to injure the timber, and endanger the safety of the mine, it is advisable to wall the shafts, particularly in those places where the water abounds. In this instance a strip of sheet lead is inserted in the wall, which forms a channel for the water and conducts it to a reservoir or the pumps. Fig. 23 represents the manner in which such strips for forming gutters are applied. It forms a screw line, and conducts the water to a place where it cannot do any further injury. Shafts lined with stones, bricks, or cast-iron, are in all cases round, and the distribution of the various compartments for

Fig. 22.

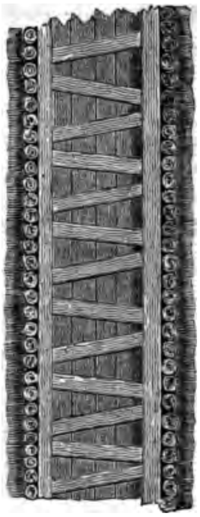
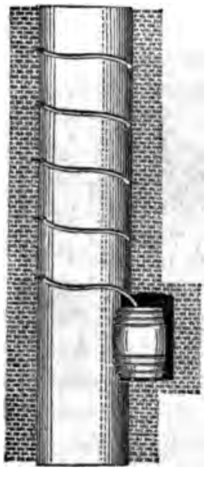


Fig. 23.



hoisting and pumps, is made according to the size of the shafts and that of the pumps. In most cases, a chord is drawn in the circle, and the space between it and its arc is used for the pumps and the descent of the workmen. The other larger space is divided into two halves for hoisting-shafts. When a shaft traverses various strata of mineral in its descent, at each stratum a chamber is excavated for the reception of wagons or cars, in case these veins are worked.

Framing of Timber.—The timber is not often employed in its round form; in such case it is necessary to remove at least all the rotten parts of the wood, and also the sap, for both increase its tendency to destruction. Young wood, such as saplings, should be rejected by all means from the interior of a mine—it is of short durability. Old wood, about to decay, is as bad as too young wood. Timber for a mine must be taken from the most healthy, full grown trees, and if possible, it should be obtained from luxurious bottom lands. Up-land timber is never so durable in mines as that from places along river banks and low lands. It is of little advantage to use the timber in its round form; it occupies more room than hewn timber, and never makes so good and durable work as the latter. It is not necessary to hew four sides and square the sticks. If two opposite sides are hewn, and the other parts freed from bark, and knots, it is all sufficient. There is no need of using the broad-axe in this operation; for a good workman can straighten timber by the use of a common axe sufficiently well. All the wood-work consists of rectangular frames, often square, as in simple shafts, or forming a tapered rectangle, as in drifts. The size of the wood is not often more than 8 inches for the heaviest kind of timbering; in most instances it is 6 inches, and very seldom but 5 inches. When timber is heavy, it causes much work to bring it into its place; and as machinery, such as pulleys or windlasses, cannot be used in most cases; and as all the work must be done by men; and further, as a large number of hands cannot be concentrated for want of room, it is inexpedient to use heavy timber. It is more profitable to multiply the number of frames or props, than to make timber so heavy that more than two men are required to put it in its place. The distance at which timbers or frames are put apart, depends on the quality of the timber, the nature of the rock, and the kind of planks which are used for facing-boards. In most cases, it may be found equally as profitable to place the timbers close together as to set them at intervals, and protect the spaces between them by planks or other material. In the latter case, the frames are never set farther than 3 feet apart, and if the facing boards are not very strong, say 2 or 3 inch planks, the distance is 2 feet and less. In all cases the frames must be placed at right angles with the sides, or the axis of the shaft or the drift. The spars, or parts, composing the frames, are commonly united at their extremities by a half check, as shown in figs. 24, 25, and 26. When round timber is used, which may be profitable where pine wood is the material, the joint is made to fit the round timber, as shown in fig. 27. In this case, long smooth timbers are posted in the four corners, and the traverses or props are braced firmly, having at their ends circular concavities which fit to the round corner pieces. Such timbering may be made very strong, but if one of the corners breaks all the others will fail; it is therefore necessary to select the most durable wood for the corners. In all cases it is desirable that the wood should retain its whole force, and therefore as few checks are made as possible.

FIG. 24.

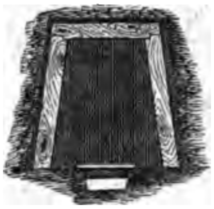


FIG. 25.

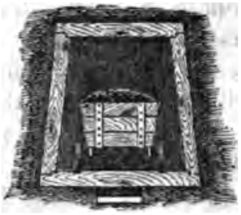


FIG. 26.

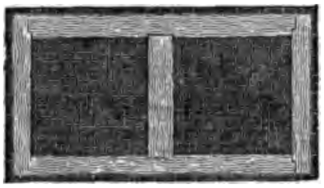
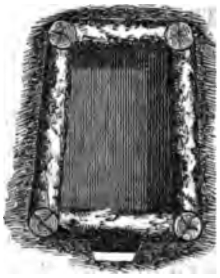
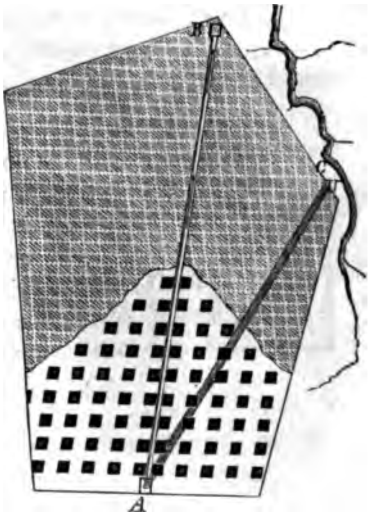


FIG. 27.



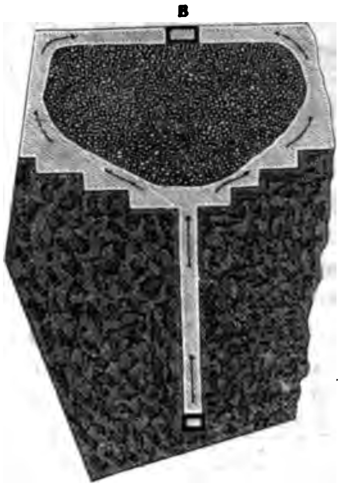
Extraction of Ore.—The veins thus explored by preparatory work, are deprived of their mineral in various ways; these are mostly similar in principle, but differ in the modes of extraction. If a vein is horizontal, or nearly so, which is the case with most of the bituminous coal-veins and the other minerals which belong to that formation, the whole of the coal-field, or space at our disposal, is divided into rooms and pillars, and the labor is carried on in such a manner as to provide a circulation of air to every stall where miners are at work. If in fig. 28, the extent of a mining property is delineated, and at A is the lowest point of the vein, the engine-shaft is to be in that point; and if a drift can be started from any other point, say from C, we endeavor to reach the point A by a dead level, and commence the work of extraction at A. The air-shaft must be at the highest part of the vein, and if that is in B, the level in the vein from A to B opens the communication between both and secures the circulation of the air. In most cases, the work is commenced at the dip and worked to the out-crop; it secures the drainage of the mine, and is the cheapest and most secure plan of operation. The rooms are opened in the whole length of the dip-head; but if this be too long, the work may be so arranged that the penetration of the miners forms a triangle towards the air-pit, so as to secure a sure circulation of air to all the work-rooms. The pillars which are left standing, form about one-third of the whole area, if the coal is solid, such as the Pittsburg vein. When the coal is hard, one quarter of the area is sufficient; but when the coal is soft, the pillars form one half of the entire mass of coal, or other minerals. The size of the pillars is not only determined by the firmness of the mineral, but also by the pavement and roof. Are these of soft material, or slaty and brittle, the pillars must be stronger than when the floor and ceiling are strong. The size of the stalls depends also on the solidity of the mineral as well as on the walls of the vein, but more on the latter than on the first. If the top and bottom of the vein are strong, the rooms may be from ten to twenty yards wide; but if these are soft or brittle, the size of the rooms

FIG. 28.



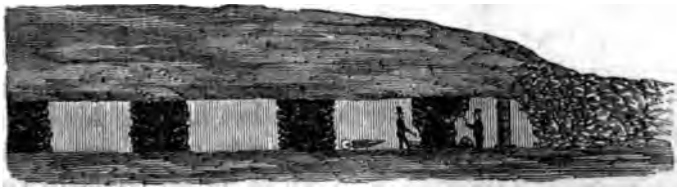
is contracted to as many feet. The larger these rooms, the more profitably the work of extraction may be done. The plan laid down here answers for all kinds of minerals, but is particularly calculated for coal. When the vein is thinner than three feet, some of the dead rock must be taken out along with the mineral so as to afford room for the miner; in these instances a different plan of working is adopted, which is cheaper in the aggregate. Thus the level from A to B, fig. 28, is opened, as before; but the miners commence working from the crop to the dip, inclining the face of their work towards the main drift so as to drain the water from the rooms. The work is now conducted on the whole width of the vein from behind, taking out all the minerals at once, and building up the rubbish towards the main drift so as to have it always open, and form a sure retreat in case of accident. The rubbish is piled in such a manner as to form air-channels from the mouth of the workings to the air-pit, and the whole assumes then the form represented in the plan fig. 29. If the width of a mining property is too extensive to be ventilated by one drift and two shafts, more drifts are excavated and conducted to the common air-shaft, or to other air-shafts. In this case all the mineral is taken out at once; no pillars are left standing, which finally may be lost if the mineral is soft, or the pavement forms creepers, or the roof sinks in. This plan is, therefore, preferable in all instances where sufficient rubbish is made to support the roof in case it sinks down. In many cases miners endeavor to support the roof by wooden props, but this is dangerous; for wood will bear a burden to a certain degree and then all at once yield, affording the roof a large space to sink, which generally breaks it up so as to injure the mine permanently, or at least cause the loss of a large quantity of mineral, which must be left standing in order to separate the broken roof from the new work-rooms which may be opened. If such accidents happen the air-shaft is generally lost, and a new one must

FIG. 29



be sunk before the work can progress again. In our country mines are not so deep as to make such particular arrangements necessary as are required to ventilate deep mines; and some centuries may pass before our descendants shall be compelled to dig deep for minerals; there is such an amount above the levels of the valleys, that no extraordinary means are required for obtaining what we want. We abstain, therefore, from describing the particular arrangements required to work a deep horizontal vein. Where pillars are standing in a mine, these are taken out when all other parts have been removed, and the miners commence from behind and work towards the engine pit, taking the pillars down, and letting the roof drop as they retire, as represented in fig. 30. This is an operation which requires sagacious and cautious workmen to succeed well, or much of the mineral in the pillars may be lost. In all cases it is of vital importance to the mine and the success of the work, that the roads and the air-passages are kept open, which are more endangered by a soft pavement than a brittle roof, or soft minerals. In order to prevent those accidents, which are chiefly caused by creepers, or elevations raised in the roads by the pressure of the pillars on the soft pavement, the ground is always taken out so far as to afford a hard solid floor, which may not give way under the superincumbent pressure. It is more safe to have the soft stratum in the pillars, for here it can be watched, than to have it in the bottom of the mine.

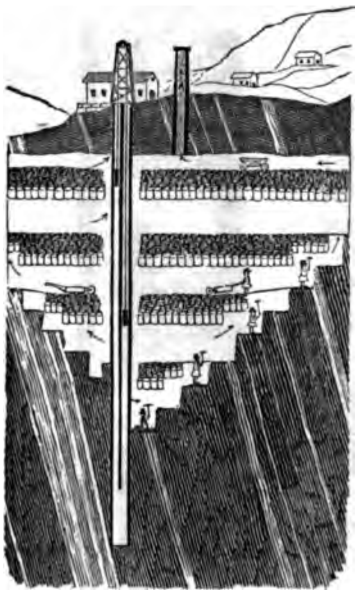
FIG. 30.



If the position of a vein is vertical, the working of it is comparatively more expensive, because of the extent of dead work which is to be performed, in order to reach the deposit. The work of extraction is generally cheaper, particularly where timber is not expensive. When a pit has been sunk to a certain depth, which depends on the quantity of ore to be raised in a specified time, there must be galleries driven for ventilation; these serve, in the mean time, as starting-points for excavation. The work in vertical veins, or nearly so, is carried on in two different ways: the one consists in attacking the mineral from above, the other from below;

both modes have their advantages and disadvantages. In either case the work is carried on in the form of steps, which may be direct or inverted. The mode of working by direct steps is represented in fig. 31. There the engine shaft may be sunk to a moderate depth, so as to secure the safety of the roof of the first gallery; in most cases from 20 to 50 feet depth is sufficient. Here the first gallery, towards the air-pit, is driven, so as to secure the circulation of air. In sinking the shaft 20 feet deeper, less or more, according to the nature of the vein, a second gallery is commenced, 7 feet high, and as wide as the vein or wider, as the case may be; this leaves from the first gallery a solid mass of 13 feet high, which protects the shaft. In driving the second gallery for 20 or more feet, the roof is in the mean time taken down, but so as to leave a part of the vein at the shafts to prevent its being crushed by the rock; for which purpose, in most cases, from 10 to 20 feet are sufficient. The mineral between the first gallery and the second gallery is now taken out altogether, and, at the same time, slanting timbers are inserted above the second gallery, upon which the rubbish from the work-rooms is thrown. The position of the timbers is more distinctly shown in fig. 33. They form scaffolds, and if the amount of rubbish is great, they must be strong, or their number must be increased. If the rubbish is heavy, it is advisable to have more than one row of timbers for each gallery, as is shown in the lower part of the engraving. At certain distances new galleries are opened, and the height between two of these is divided into steps of about 7 feet each, so that each workman may reach conveniently to the whole height allotted to him. All the rubbish from the work-rooms which belongs to one gallery is piled upon those timbers which support the gallery. The rubbish forms thus one gallery for each commenced in the solid vein, started at the shaft,

FIG. 31



and it serves, in the mean time, for carrying the ore from the work-rooms to the shaft, and for conducting fresh air from the shaft to the air-pit. A temporary platform for a wheelbarrow track, or for a hand-cart, is laid from one of the steps to connect with the surface of the rubbish, for one tier. The work may be started at once on both sides of the shaft, and sufficient mineral can be obtained when the number of miners, requisite for that amount, find room to work. It is easy to perceive, by referring to the engraving, fig. 32, that in sinking a shaft into the vein itself nothing is gained. It causes, also, danger to the workmen, and may injure the mine, if the pillars of mineral supporting the shaft are crushed; besides, a part of the mineral is always lost in such an arrangement. It is necessary that a shaft should be always in the hardest and most solid part of the rock, in order to secure its permanency, and afford the means of sinking it continually deeper. The arrangement is then as represented in fig. 33. From the shaft galleries are driven towards the vein, and from them the work is carried on as described before. In this manner, a solid strong wall is secured to the shaft, all the mineral

Fig. 32.

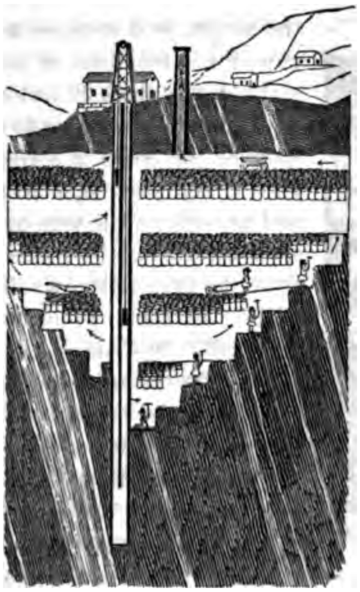
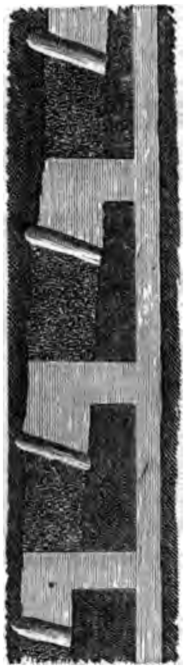


Fig. 33.

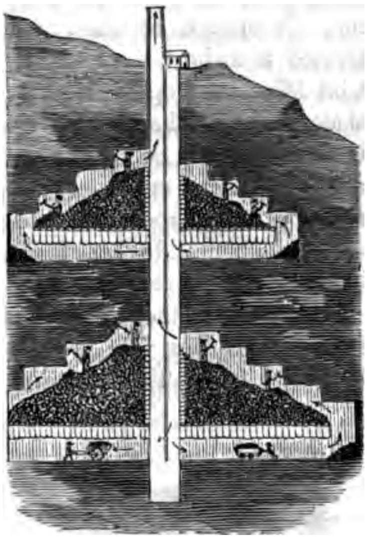


may be taken out at once, and, whatever may happen to the mine, the shaft is always safe and ready, and in good order for work.

This mode of mining by direct steps has its disadvantages, in consequence of which the work goes on slowly and is expensive; the water, coming down the steps, is generally troublesome, and in the progress of work every piece of mineral must be picked by hand. In hard minerals it affords advantages, because it may be blasted to better advantage in this form than in inverted steps. In thin veins the distance from one gallery to the other cannot be so great as in thick veins. In the latter case, we observe a hundred and more feet depth from one to the other gallery. The cross-timbers which sustain the rubbish are always exposed to early destruction, in consequence of the mass of water which generally comes down the walls, added to the pressure of the rubbish from above; and as the prospects of the mine depend upon the durability of these timbers, which secure the passages in the mine, it is imperatively necessary that the wood for these should be of the best kind, and well prepared. It is, however, not necessary to have all the timbered galleries so strong as to resist crushing or decay. Some of them may drop without harm to the mine, but galleries leading to important parts of the vein should be durable, and the best timber selected for these entrances. Where timber is scarce, or consists of pine wood, which is not durable, it is advisable to form the roof of a gallery of part of the vein, that, in case an accident should happen, there still may be a basis upon which a gallery can be opened. The mineral thus remaining may be taken out when that gallery, to which it belongs, is to be abandoned.

The mode of working by inverted steps, or stopes as they are vulgarly called, is represented in fig. 34. The pit is sunk and the work is carried on by similar means as described before for right stoping or descending steps. Here is, however, no gallery leading to the air-shaft, and if the hoisting, draining, and ventilation is done by one shaft only, there must be arrangements made in it for these purposes. The fresh air is in this case conducted down in one part of the shaft, and the impure air extracted from the mine by another part of it. The labor of extraction is here more simple and convenient, as in descending work there is no necessity of driving galleries to the air-pit. With the opening of a gallery the work of extraction is commenced, and may be continued uninterruptedly until the whole mass of ore is removed which exists between two galleries. This, however, requires very strong timbers, or stone arches, in order to prevent the crushing of the roof, because the galleries when lost in these mines can hardly be recovered. Strong timber is the more necessary, because all the rubbish made in these rooms rests upon the roof of the gallery, and will soon crush it if not well protected. The timbers, if laid close together, should be covered with strong planks or good split rails, so as to afford an opportunity of changing a decayed piece in case any is destroyed. This mode of working has one serious drawback to its advantages; mineral and rubbish drop together, and the latter can hardly be separated from the first in the dark of the mine; and as the surface of the rubbish on which the miner stands is uneven and full of cavities much mineral may be lost in it, or a great deal of rocky matter is hoisted along with the ore to the surface; and as the latter is here requisite as well as in the preceding case, for the support of the walls of the vein, it is necessary to retain as much of it as possible. At convenient distances small openings are left in the roof of the gallery through which the mineral is thrown down, in order to be loaded in cars and transported to the shaft. In other instances the roof and the gallery is pushed forward as the miners advance, and the minerals thrown down at the farthest end of it, as represented. This latter mode of working by steps is suitable for coarse and pure minerals, such as coal and iron ore, and in fact any mineral which is compact and breaks in lumps, and which is not very valuable. But valuable minerals and those of a fragile nature should be worked by descending steps, in order to secure every useful part of it.

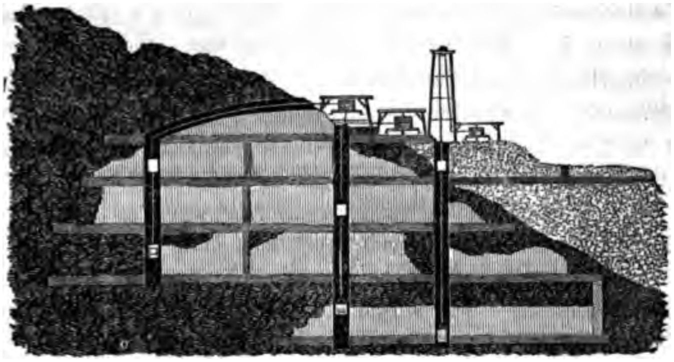
Fig. 34.



Instances in which the veins are of such a nature as to admit of either one or the other mode of working at the same time are frequent; in these cases a sufficient number of galleries are opened at once, and the work carried on as conveniently as the locality will admit. Where a number of shafts is requisite in order to hoist and ventilate, a number of independent rooms may be opened at once, and a large quantity of mineral extracted in a short time. In fig. 35 we represent a profile of the Cliff Mine, at Copper Harbor, Lake Superior, in which three shafts and a level serve either for hoisting or ventilation, or for both purposes. So many entrances to a mine cause, as a matter of course, heavy expenses; but it may be found necessary where the work in the rooms is naturally tedious, which is the case in native copper, and where fire is applied to the rock to make it brittle and more easy to work.

All these methods have their peculiar advantages, which are apparent when a vein is fully explored and its character thoroughly known. The ascending steps cause sometimes hard work to the miner, because he is to use the tools mostly overhead, or work in a position not favorable to the best application of his power; there is, however, this advantage, that material which is once loosened detaches itself and drops by its own weight, thus acting with the efforts of the miner. In this instance less timber is required than in others, which not only saves the labor of chopping, hauling, and dressing it, but saves also the labor of putting it in the mine. On the whole, we may conclude that the working in ascending steps is more suitable to produce cheap minerals than the descending work, and it may be the better plan of operation in this country.

Fig 35.

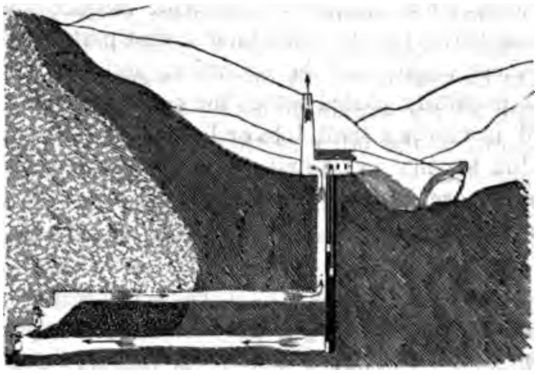


Masses.—The extraction of masses of mineral from the interior of the earth is often connected with considerable expense and difficulty. Experience has settled this question so far as to determine that the extraction of a mass is most profitably and safely accomplished by taking it out from below,and if possible from the lowest point, at the commencment. Masses, however, are often so extensive, that to reach their lowest parts is beyond the means of those engaged in the operation, and the work of extraction is generally started before the greatest depth is arrived at. In all instances a shaft into or beside the mass, or a level as low as the locality will admit, is a condition of success. The veins of silver ore in the Southern States, or in California, and the lead ores of Missouri, and other mineral deposits, may extend so deeply that centuries are required for their full exploration; this, however, is no reason why correct principles of mining should not be applied. Any ore-vein, and a mass particularly, should not be worked from above; it deprives the miner of the comforts and security arising from a good roof. When the surface of the ground is once broken by digging a cavity into it, that cavity will be always a reservoir for the surface waters, and as these are the most destructive to timber, annoy the workmen in their descent, and cause bad air, their access to the interior of a mine should be prevented by all means. A mine may be permanently injured by destroying that covering which prevents the water from entering the vein. In all instances the work in the interior is more expensive when exposed to the influence of the surface waters. If this is so serious a matter to veins, it is far more so to masses, because in the first case we may form a fresh roof by going deeper and lose a part of the vein; this however is impracticable in a mass, or if attempted the losses are severe; for in this case no natural or artificial roof can be formed sufficiently secure to admit of the extraction of all the minerals contained in the mass.

When a mass is so located as to admit of a shaft or drift in the surrounding dead rock, that is adopted in order to protect the preparatory works. It affords safety to the workmen, and admits of the extraction of all the minerals, at least those which are above the drift or the bottom of the pit.

In fig. 36 we have represented the manner in which masses may be most profitably extracted. The shaft is sunk in the dead rock, and two galleries are at once driven, one from the bottom of the pit to the lowest part of the mineral, and the other at some distance above it, which latter serves for the extraction of foul air. A communication is cut through the mineral mass which connects the two drifts, and secures ventilation. The whole body of ore is now taken out at once, no pillars are left standing; the excavation nearest the workmen is secured by wooden props, which are moved as the miners gradually progress. In order to secure the safety of the roof, and prevent the sinking of the whole mass, all the rubbish which is made in the mine is piled behind the miners, and firmly wedged in between the floor and the roof. If sufficient dead matter is not furnished by the mine, hard stones, gravel, or rock, are sent down from the surface, and carried in cars to the air-gallery, and unloaded in the mine. It may thus happen that, if not much rubbish is made in the mine, a stone quarry must be opened at the top of the pit in order to obtain matter for filling up. In all instances, not more space is left unoccupied by filling than is necessary for the miners to work in, and to serve as a drift for the transportation of the minerals. In this manner all that mineral between the two drifts is removed, and the height of the roof of the mine is equal to the height of the roof of the second drift from below. When all the mineral is removed, the lower level is filled with rubbish, and shut for ever. Previous to closing the lower part of the mine, a third drift is started from the shaft, into the mass, and set in connection with the second drift, so that a circulation of air is provided for before the lowest level is shut altogether. In this manner the work is carried on successively until all the mineral is removed. We cannot, here, work in different heights at once; all the forces

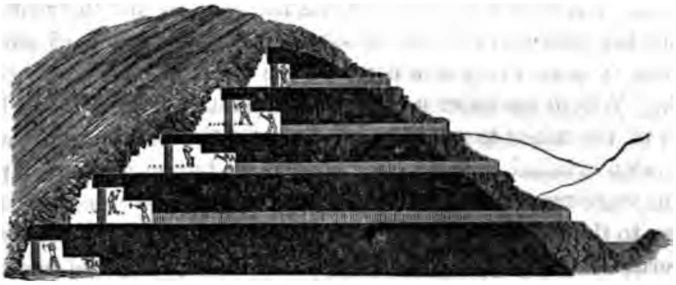
FIG. 36.



are concentrated in one story, or space; and if we are compelled to furnish more mineral than possibly can be extracted by these means, it is necessary to work on a different plan, which is neither so convenient nor so profitable as the first. In this instance we commence the work of extraction at once, in different levels, and take out rooms of a certain size, according to the quality of the mineral; these rooms are generally provided with arched roofs cut into the mineral mass. Around such a room a wall is left standing in order to sustain the roof, and the pillars thus formed must support one the other as they rise upon themselves. In this manner about one half of the mineral may be taken out of the whole mass; and if the mineral is hard and strong, it may last until the vein is exhausted, after which the miners go down into the lowest part again, and endeavor to remove the pillars; provided these have resisted the pressure from above and are not crushed. This kind of work is expensive; it needs no timbers, but the digging is hard, because the miners must cut most of their minerals loose at two sides, while on the former plan one side only is to be loosened.

Another mode of working a mass, which is more profitable than either the first or the second, is represented in fig. 37. The mass is penetrated by levels from a hill-side, if accessible, which are driven through it, or by shafts in the dead rock. These levels reach as far as convenient, or penetrate through the mass. On each side, at the farthest end of the drift, rooms are opened, of such a width as to make it convenient for the workmen. The width of such a room may be two or three hundred feet, according to circumstances, having the drift for the discharge of the ore in the middle. The face of the workroom slopes gradually towards the extreme width, in a similar manner as steps in a vertical vein, with this differ-

Fig. 37.



ence, that the steps here are vertical, and in the rooms horizontal. If the mass is heavy, or thick, a succession of levels may be driven one above the other, or parallel galleries made in the same level. These rooms are sufficiently high to afford space for two or three sets of hands at once, the one working above, and at the same time behind the other, as shown in the drawing. This kind of work may be done cheaply, after the dead work is performed; the latter, however, is generally expensive—it requires no timber, no filling, and no mineral is left in the mine. It is the most practical form in which extraction can be accomplished, but demands dexterous workmen to avoid dangers, or at least to escape before those accidents happen, which are necessarily connected with this method. We think it the most suitable form of work for the daring American.

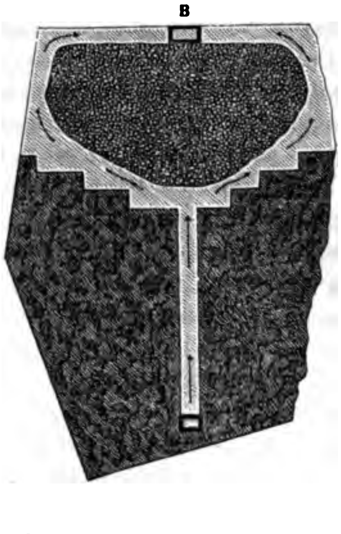
Not only masses, but veins, may be worked by these means; most of the Western iron-ore veins, in the coal region, are now worked on this principle. The miner opens a drift into the out-crop of an argillaceous ore-vein, and continues it as far as the ore is oxidized, or transformed into hydrates; here he stops, and opens on each side of the drift a room sufficiently wide to afford a certain quantity of ore, but in the mean time he secures a safe retreat in case of an accident. He takes out of these rooms the ore as fast as possible, supports the roof partly by props, or if he has sufficient rubbish, throws it behind into the places he leaves. The roof may now come down; but it will rest on the rubbish. Where the latter is scarce, great caution is required on the part of the miner to support the roof; for the best wooden props are often crushed at once, and he may be buried without a previous warning. When a quantity of dead matter is raised up close to the roof, the latter cannot sink far; it is not so heavy as to crush the wood. In all cases, however, it requires a sharp ear and quick eye to escape the falling roof; and if the distance of the miner from the drift is too far, or the passage to it is impeded, the most attentive workman may perish in the attempt to escape. All rocks give warning, issue a certain peculiar sound, and an experienced miner knows by this sound, where, and how much of the roof is coming down. It is therefore essential that all noise and disturbance of the workmen should be avoided, in order not to draw their attention from these objects.

This manner of working masses or horizontal veins, is applicable only in those localities where little or no fresh air is needed.

A circulating motion of the air by means of connecting channels is not possible here, and the supply of fresh air depends entirely on that which may be forced into the mine, by means of the engine. A faint circulation is produced by cutting the drift considerably higher, and by putting up a broad ceiling or double roof, and forming a channel in the upper part for the extraction of foul air. The channel may be connected with a chimney, or an extracting engine. This requires a high drift, and, in case the mineral is soft, long timbers; and as the power applied for extracting the air is also expensive, this mode of mining is cheap only under peculiar circumstances. Mines which do not produce bad air by themselves, and where the number of hands employed is limited to two or four, may be worked to great advantage by these means. Mines which produce bad air, and where the number of men employed is considerable, require means of ventilation to be provided in some manner. Artificial ventilation may be used, but it is always, and especially in this case, expensive. It is also ineffectual, if not properly constructed.

In most instances, particularly in ore-mines, sufficient rubbish is made to erect some walls, and fill the spaces between them. Where less rubbish is produced, as in coal mines, there is not sufficient to form walls, and in order to fill a large part of the area of the mine, stones must be quarried outside. These are carried by the returning cars to the work-rooms, where they are placed in the proper position.

Fig. 38.



The plan of a mine assumes then the form represented in fig. 38, and may be ventilated by an air-shaft erected at the farthest end of the mine. A spacious drift may here conduct fresh air to any number of workmen, and where material for filling is cheap, it is the better plan of working any mine of horizontal extent. All the minerals are here taken out at once, and there is no necessity for keeping those parts in repair which are partly, but not quite, exhausted. Such repairs are expensive, and require constant attention. Where cheap material for filling may be obtained, this plan of working any kind of mine is most profitable, and the best suited to our country.

The principle of working any form of deposit is then the same in all cases; it consists in taking out all the mineral at once, and filling the spaces partly with rubbish, either from the interior of the mine, or taking it from some place outside convenient to the mouth of the mine. This kind of work may answer almost in all cases where ores are taken out, but for minerals which cannot bear much expense, such as coal or iron-ore, it is doubtful if it is the best plan. In the western coal basins a bushel of bituminous coal pays from one cent to one cent and three-fourths to the miner; and it may be asserted that, at that rate, not much rocky matter can be introduced into the mine. It may be remarked, however, that in all these localities, rock is cheap, and may be brought into the mine at the same price at which coal is taken out; and not one-fourth of the weight of the coal dug is required to fill the mine. When we consider that most of the mines suffer from a bad roof or soft pavement, which compels the miner to leave uncommonly strong pillars of coal; that also, he is frequently compelled to allow coal to remain on the roof and floor for his own safety; and consider further, that these mines often break down, notwithstanding these precautions, and bury all the coal in the pillars, roof and pavement; we are authorized to conclude, that at least one-fourth in all cases, and in some the entire half of the mineral is lost to the owner and the community. To carry stone or shale into the mine, equal to one-fourth the coal extracted, would increase the expenses per bushel 25 per cent. The full amount of this may be saved in most cases by the miner, particularly where he is compelled to work in small rooms on account of soft pavement and roof. In the manner proposed, he has a large room, the car for loading close at hand, needs little or no timber, and has at all times an invariable supply of fresh air. The owner of the mine saves a great deal by this mode of work; he is sure to extract every ton of coal in his field. If an acre of coal of the Pittsburg vein contains 600,000 bushels of salable coal, and but 300,000 bushels are extracted, the owner loses actually the one half. In many instances, but 200,000 bushels have been removed, when the mine broke down. If a bushel of coal is worth but one cent to the owner, which is the general price, and he loses $3,000 worth of coal in an acre, he may spend part of the inevitable loss to prevent it. If the owner were to pay all the expenses of stones for filling and the miner nothing, he would still be the gainer at the rate of 25 per cent. on the value of his property. It is therefore evident, that in all cases this is, to the miner, the most practicable mode of mining; it is the most profitable to the owner, and is a benefit to the community and to our descendants. All useful minerals which are lost by wasteful individuals in dead mines, are lost to the community. The German miners call such kind of mining "Raubbau,"—robbery.

Pockets, nests, or concretions, are generally distributed in larger masses of vein-stone; we find them, however, in the form of small veins injected in the crevices of the rock, such as galena, in the fractures of slate. When such small bodies of ore are distributed in large masses of distinct rock, which latter compose a vein or mass in the general formation, the mode of working is similar to that described above for veins; and if the dead matter of the vein, which necessarily must be quarried in order to obtain the mineral, so far predominates as to make the amount of ore yielded by the vein too small to pay these expenses, the mine must be abandoned. It is in these instances that the well-informed miner can show his superiority to the mere laboring man. The latter will follow any tract of mineral with sanguine expectations of increase or good chance, and he is often led to labors which never can be repaid. The failure of such enterprises discourages others who are better situated, and who may be induced by their ill success to abandon good positions. A well-informed miner knows by the nature of the mineral, and by the appearances of the accompanying vein-stone, how much mineral the vein, on an average, may yield. He will form a well-digested plan of working the mine, and if he finds the amount of mineral which may be raised, by expending a certain sum in dead work, will not pay the latter, he abandons the project altogether. The simple working miner, who has not knowledge enough to judge of the nature of the rock, must follow where his senses lead him; he cannot arrange a plan for systematical work, so as to reduce the expenses of extraction; he takes out what he can see and reach without regard to expenses and consequences. It is easily perceived that the work of extraction, carried on from the top of a vein downwards, can be prosecuted only to a very limited depth, and all the rest of the mineral below must be either lost, or extraordinary expenses are required to recover the mine. Such work at the top of a vein is very expensive in its nature; all the rock and vein-stone must be dug by bits and by means of the pick; no facilities are afforded to the miner in the advantages arising from gravity; no roof is there to protect him against injury; all the rubbish must be at once removed to some distant place; and all the water which may enter his digging concentrates to annoy him. These are the causes of abandoning many of our ore mines, particularly the copper mines along the Atlantic coast, after expending a great deal of money. There are, no doubt, some good mines among the lost ones, but the general ill success which accompanied most of these enterprises has caused so much distrust, that good and bad are condemned promiscuously. When the lead miners of the rich Missouri district dig merely a hole and remove the ore so far as they can reach, there is no wonder the ore is expensive, and the business suffers in the midst of profusion. The gold-ore diggers in the Southern States are generally in the habit of digging a ditch, sometimes even a deep ditch, and make good wages during that time; but they soon find their expenses so heavy that they cannot go further down, notwithstanding the ore may be equally as rich in the deepest parts as it has been at, or near, the surface.

All these difficulties may be avoided by systematic work, and by forming a correct plan and estimates at the outset If one individual does not possess all the knowledge requisite to form such a plan, a number of men united may concentrate sufficient intelligence to accomplish it. The working of a mine is not different in principle from any other business; no sensible man will build a house without laying down a plan before he commences the work, nor engage in any business without calculating the cost and proceeds of it. If a man ventures to build a steam engine without knowing any thing of the principles on which it is constructed, or of the manner in which it is put together, he may surely expect to make a failure; he will lose both the machine and his money. It is exactly the same in mining; and as the means for obtaining the knowledge required for mining are not afforded in such abundance, and cannot be obtained with equal facility as those which furnish a knowledge of steam engines, we may naturally expect there will be a less number of men well informed on mining than on the steam engine.

Practical Remarks on Mining.—The operation of mining is divided into two distinct branches; the planning of it requires a different kind of knowledge from that of working a mine; both united are the only means to secure the success of the enterprise; neither one nor the other by itself is sufficient to depend upon entirely. A cubic yard of limestone may be quarried at an expense of 30 cents, if no stripping is to be done; the removal of earth or rubbish of course increases the cost of it, which may, in many instances, bring it to 75 cents. Sandstones of the coal formation may be worked at the same price as limestone, and often as low as 20 cents a cubic yard. Shale, or slate, may be dug at 10 cents a cubic yard. Granite, trap, gneiss, and porphyry may cost as high as $3 per yard if it is to be broken; stratified hard rock from $2 to $1. Similar prices govern the work in a mine. To these prices, however, we have to remark, that in digging a shaft of small dimensions in hard rock the expenses per yard are considerably higher than in a wide shaft, and far higher than in the open quarry, or in a vein which has a good undermining. A cubic yard of granite or trap cannot be taken out of a four feet shaft for less than $12; from a larger shaft at from $6 to $10, and from a vein with good undermining it may be removed for $1. These prices are chiefly regulated by the amount of work caused to the miner in separating the stones from the mass of the rock. A shaft may be sunk in sandstone at the rate of $6 and from that to $3 per cubic yard; in slate, shale and gravel, at from $2 to $1. These prices are all exclusive of timbering or walling. A drift in granite or unstratified rock is quite as expensive as a shaft in that kind of rock, but in stratified rock it may be done cheaper. A cubic yard of the rocks of the coal strata may be removed at $1 50, or $1. In these prices are included the sharpening of tools, and the removal of the fragments to the mouth of the pit. When timber is required, for supporting shattered rocks, the miners are under obligations to put it in without extra pay. The prices paid to the miners for digging minerals, varies of course greatly; but we may always calculate upon the amount of rock and the mineral which must be removed in order to make the work profitable. When a vein of coal is very hard, has no undermining, and requires much cutting in hard matter, a ton may cost $2 to dig it; if a similar vein of coal contains a seam of soft mineral, it may be raised at $1, and even at a less price, if the vein is strong and gunpowder can be applied. Bituminous coal, with a good undermining, and 5 or 6 feet vein, can be dug at 20 cents per ton, exclusive of hauling. The average price, however, paid for digging bituminous coal, is from a cent to a cent and a half per bushel, which brings the ton to from 25 cents to 37 cents. The prices paid for hauling vary according to locality. If the distance is long, and the means of transportation imperfect, a ton may cost fifty cents for hauling it from the rooms to the mouth. of the pit; are the means convenient, such as large cars, railroads, and the drifts and galleries high enough for a horse, a ton may not cost more than eight or ten cents from the rooms to the mouth of the pit. A cubic yard of brittle matter, if veinstone or ore, may be cut loose by the miner at the price of 50 cents and less; slaty rock at the same price, and from that to $1. Rock which must be blasted and broken, will cause an expense of $1 to $2 per yard. A good undermining facilitates in all cases the work, and reduces these prices considerably.

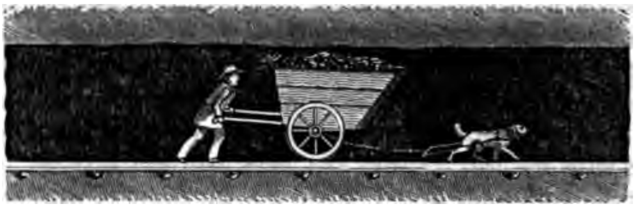
Blasting.—Gunpowder is the most valuable agent for excavation; it is however of more service in the work of extraction than in that of preparation, because in removing the minerals those regular forms of the walls are not required, which distinguish the shaft and the drift from the gallery. Blasting-powder is employed in different quantities and in various forms, according to circumstances. In slaty open rock, in rotten brittle shale, and in loose gravel, it is of no use; but in hard rock, in sandstone, limestone, and similar substances, blasting is extremely serviceable, and often reduces the prices of working hard rock to that of soft material. Gunpowder is of most service where the vein has a seam of soft mineral, or a succession of cavities on one side, so that a blast applied at the opposite termination of the vein may remove the whole thickness of it. If the soft matter or the cavities, are in the middle of the vein, it requires always two blasts, and of course the drilling of two holes as well as two charges of gunpowder, to remove the vein. The amount of gunpowder used is often calculated to be proportionate to the amount of rock removed, but this is not so in practice; where the amount of matter removed is limited, the consumption of powder increases more rapidly than the quantity of rock removed. In mines which have a large quantity of shattered rocks, the application of powder is limited by the consideration that injury may be caused to other parts of the mine. The removal of thick veins, or masses, or heavy rock, also veins of pyrites, is often connected with considerable difficulty, because heavy blasts cannot conveniently be applied. In all such cases it is, however, the cheapest way of working masses; and if holes for blasting cannot well be drilled, they can be formed by acids. Pyrites may be penetrated by nitric or muriatic acid; also native metals, such as copper, limestone, and magnetic iron ore, may be dissolved by any acid—the muriatic is, however, the most generally used. In this case we cannot sink any other form of hole than a vertical one. The manipulation is easily performed by setting a glass tube vertically upon the rock, and providing its top with a funnel and apparatus, so as to let in the acid drop by drop. If the pipe is close fitting to the rock, and the acid poured in very slowly, the hole will not be much larger than the glass-pipe. The tube must descend with the bottom of the hole, and be always close to it. This operation works very slowly; but in pyrites, or compact magnetic iron ore which cannot be penetrated by steel tools, it is a useful method of preparing a hole for blasting. When heavy masses are to be detached by one charge, the hole may be made wider in the bottom by letting down the acid more rapidly, which will spread over a larger surface and dissolve a greater width.

CHAPTER V.

Hauling and Hoisting.—The mineral, after being detached from the mass of the vein, is carried to the mouth of the pit by various means. This kind of work is generally performed by laborers who are not miners; and if it is included in the contract of the miner, it is given by these to other parties who perform it for them.

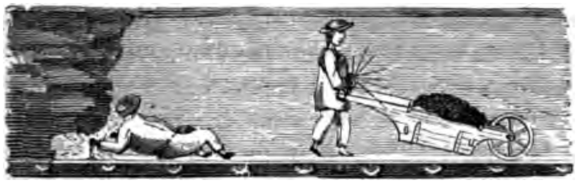
Dog-cart.—One of the most common means of carrying minerals from the wall-face to the bottom or mouth of the pit, is the dog-cart of the coal mines. It is a convenient and cheap mode of transporting mineral in the subterranean passages, and we entertain serious doubts which is the cheapest—that by horses on the tram-road, or that by dogs on the plank-road. In fig. 39, is represented a cart which is in general use in the Western *coal mines.* It is about three feet high, with light wheels, and the capacity of its box is about half a ton weight, or twelve bushels of bituminous coal. Oak planks are laid lengthways in the drifts and galleries, to form a track for each wheel; and where the floor of the mine is muddy, or a drain is made in the middle of the road, a plank is laid for the man and dog to walk on. When this road is kept in good order, a strong, heavy dog will pull the whole load easily, and the man has no other labor to perform than to direct the cart and keep it on its track. When it has arrived at the depot—either at the platform near the mouth of the pit, or at the depot of the hoisting-machine—the dog turns aside, the cartman raises the handles of the cart and discharges the load. This apparatus is very convenient and performs cheap work; the cart can be brought close to the miner without any particular preparation; it will run on a rough pavement when required, and does not need planks to be laid in the rooms where the miners are at work. A dog moves fast, and if a quick driver is with him, a dog and man perform almost as much work as a horse and man, and without requiring so much preparation in roads and wagons as the latter. The form of the plank-road, as we commonly find it—that is, with the planks laid longitudinally—is objectionable; the planks are never in order, the end-joints never fit well, and the men have almost as much work in keeping the road or planks in place, as in carting the mineral. Besides these disadvantages, the planks do not last long; the wheels soon wear a groove which causes them to split. In many mines the planks are laid crossways, as on common plank-roads, so that the wheels traverse the fibre of the wood. This is a far more judicious plan; the planks last longer, and the road is easier kept in order; the dog pulls stronger, and his feet are not so liable to injury. This latter plan of laying roads requires some more planks than the former; but when the greater durability and easier work on it are considered, there is little doubt as to the advantages of the cross-laid plank to the plank laid longitudinally.

FIG. 39.



The Wheelbarrow.—In many instances, it is not profitable to make use of a large cart, because the amount of mineral is small, or the distance short; the wheelbarrow is then resorted to as a means of transportation. This method is expensive, and if it can be avoided, it should be, by all means. In short drifts, or in preparatory work where not much rubbish is made, or in small veins where little mineral is raised, the use of the wheelbarrow is excusable, but in all instances where one man finds full employment in wheeling, the cart should be used; for, without a dog, a man can perform three times as much labor with the cart as with the wheelbarrow. If there is not sufficient work to employ the cart constantly, it is advisable to let the man rest, or do some other work in the intervals when not hauling. At a mine there is always work, and the less the number of hands the better. Where an improvement in machinery or tools can be made, it should be done by all means, partly to reduce labor, but chiefly to perform more work in the same time and in the same space. If a laborer is not fully employed in transporting mineral, he may watch the drains, keep the road in order, and attend closely to the miners, so as to remove all the loose matter which may be in their way. The common wheelbarrow is an impracticable vehicle in a mine; canal barrows are better, but still they are too heavy and large for small rooms. A wheelbarrow must be low, and light, so as to be easily loaded and unloaded. The physical force of a workman in a mine is soon exhausted, if his strength is taxed as much as in the free air. The moisture of the mine, and the bad air, soon reduce the energies of the subterranean workman. In fig. 40 is represented a wheelbarrow, made entirely of 1½ inch pine plank, with the exception of the wheel, which should be a common wooden wheel, light and strong. Cast-iron wheels are in frequent

Fig. 40.

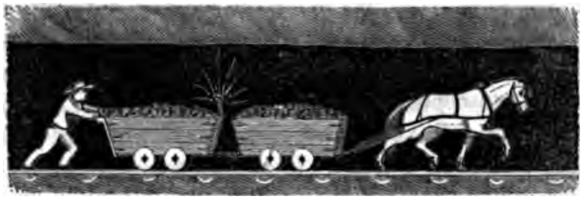


use, but they are objectionable on account of their weight. Both sides of the barrow are formed by planks, of about 4½ feet in length, and the bottom is provided with some strips of strong hoop-iron which pass across the sides, and hold them to the bottom; these protect the bottom, and prevent the splitting of the sides.

Horse Wagons, or Cars.—Where a large amount of mineral is to be transported, such as coal, horse wagons provided with four iron wheels are used. In this instance iron rails or wooden trams are laid, the latter if the amount of mineral is limited and the iron liable to be corroded by the waters of the mine. This mode of transportation is chiefly resorted to in the central drifts, where the full force of a horse or mule can be employed, so as to transport a large quantity of material over one tract. When a road is kept in good repair, and the rails are laid gradually descending in the direction of the discharge, so as to afford to the horse equal labor in pulling the loaded or the empty wagons, a horse may pull four wagons either way; and if the distance to which the mineral is to be carried is known, it may be easily calculated how much a horse can haul in a certain time. The descent of the road, from the workrooms to the point of unloading, is then 2 feet in a 100 feet, which affords in the mean time more than sufficient fall for the discharge of the water. When the descent is more than that, the horse cannot draw four empty wagons; and it is of no use to calculate on the transport of loaded cars, when the unloaded cannot be brought back on the same track. In most instances we see one horse attached to two wagons, which indicates too much or too little descent in the road. The form of rails in most common use, is that of the flat wrought-iron rail, fastened to continuous sleepers of wood, the latter laid upon cross sleepers; the rails are in this case flat iron of 2 inches by ½ or ⅝ of an inch, and from that to 1½ inch by ½ inch. Outside the mine, there is no objection to this mode of laying the rail; but in the interior, where the road is subject to frequent alterations, this form of road is expensive. In the interior of the mine it is more convenient to use flat rails edgeways, and fasten them in iron chairs and on cross sleepers, or to fasten the rails directly to cross sleepers. The angular cast-iron rail is also in use, but not extensively. It deserves some consideration on the part of the miners to determine if a well laid and graded plank-road is not the cheapest form of road in the interior of the mine; it certainly is the most convenient. It is cheaper than the railroad, and if the wheels of the cars are larger than those on railroads, and the horse is made to walk in shafts so as to guide the cars, he may perhaps pull as much on the plank road as on iron rails.

The size of the wagons is always calculated so as to take one ton of mineral. This requires a capacity of 25 bushels for heavy bituminous coal, 20 bushels for anthracite, and from 12 to 16 bushels for iron-ore and other minerals. In order to have the box of the wagon as low as possible, its area is increased as far as practicable, and the wheels made low. High cars cause a high lifting of the mineral in loading, which is tiresome to the workman, and makes slow work. The loading of the wagons is generally done by the miners themselves, the trammers or drivers merely hitch to the loaded cars and return with the empty to the rooms. The cars are generally provided with a door in the bottom, or one of the ends is attached with hinges so as to admit of its being opened for unloading; for these reasons one of the wheel axles is generally near the middle of the car, which facilitates the unloading of it by the driver; the two axles are also made close together, which causes the wagons to run with more ease on the road. In fig. 41 is represented a train of cars, which needs no further explanation. The axles of the cars are generally made of square wrought-iron bars, of 1½ or 2 inches thick, fastened to the wagons, the wheels turning about the axles. The wheels are of cast-iron, often dish-shaped, and at other times provided with spokes. The bore in the centre of the wheel is formed by inserting a turned and well-polished iron, or steel core, in the mould before casting the wheel. By this means the bore is made perfectly round, hard, and durable. There is no need of chilling the flanges of the wheels, for the abrasion on the rails is not so much as to cause any serious damage; the circumference of the wheel will always last as long as its nave, and there is no need of its being more durable than that.

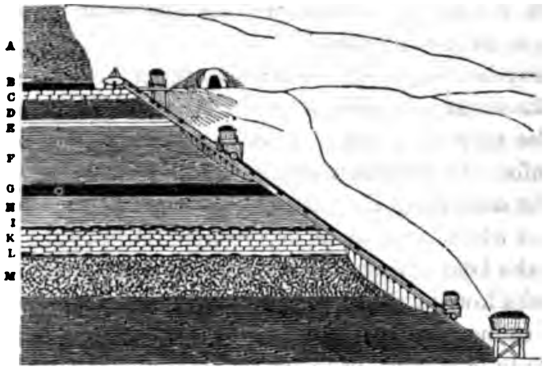
Fig. 41.



There are various other means of transporting mineral in the interior of mines, such as hand-sleighs, baskets with slips, or baskets carried on the backs of men or females. These means are not employed in our mines, and we should be sadly disappointed in the character of our citizens if they ever resorted to this mode of transportation which degrades human intellect and human power. It is preferable to let all the minerals remain where they are than to require men to debase themselves for their extraction. If mines do not pay enough to afford manly employment to miners, that is, to require of them only such labor as cannot be performed either by machines or by animals—labor in which human intellect is exercised—it is better to abstain from mining. There are machines, sleighs, or cars, in use in the European mines, to which a man, boy, or girl, is hitched by means of a strap; they work in low galleries or drifts on their hands and feet like quadrupeds, and for no other reason than that it would cause a little more expense in excavating a spacious drift, when animals or machinery might be used for the same purpose. The forms of barrows, cars, and wagons are various, to suit the special purposes, or meet the fancies of the superintendent of a mine. It would lead us too far to notice these varieties.

Inclined Planes.—Most of our mines are located in elevations high above the water level of the country, and are worked by means of drifts. The mouth of such drifts is frequently in hill-sides which are too steep for roads, or if accessible by them, the transportation on a road would be too expensive for the mineral; in these cases an inclined plane is used, on which the wagons are run down by their own weight, and are checked by a rope and brake. In fig. 42 we represent such an arrangement as is generally used at the coal mines. The brake is at the mouth of the pit, and the cars which come down the plane are either used in the mine, or are loaded at the mouth of the pit

Fig. 42.



by tilting the contents of the dog cart into them; the first, however, is the more general plan. The rope by which the cars are lowered is slung around a drum or pulley, which is checked in its motion by a brake. One end of the rope is fastened to a loaded wagon, and in letting it down, the other end brings up an empty wagon to which it is attached.

In the illustration we have selected a spot at the Kaskiminitas river in western Pennsylvania, showing in the mean time the succession of strata from the top of the hill down to the river's surface. A is a layer of shale and sandstone, often 100 and more feet thick, frequently interspersed with small veins or nodules of iron ore. B is a vein of coal, 5 feet thick. C limestone, 20 feet. D iron ore, from 2 to 3 feet thick; this is argillaceous ore, often in balls, but generally in a continuous vein of fine quality. E a vein of fire clay. F sandstone, 60 feet. G coal, from 3 to 4 feet. H shale, 20 feet. I iron ore, 6 to 8 inches. K fossiliferous limestone, 5 to 10 feet. L iron ore, 4 to 6 inches, of a very superior quality. M a vein of excellent hard sandstone, and from that to the river is shale, frequently interlined with small nodules and veins of iron ore. This section, which lies between dams No. 2 and 3, shows with how much prodigality nature has distributed the minerals for the manufacture of iron in that part of the country. This is the more apparent when we consider the immense extent of the coal formation, which is uniformly of the same character. The above section is not particularly selected for its abundance, for there are localities which afford more minerals in the same space, but it may be considered a fair specimen of the western coal field in its lower strata.

Hoisting in Shafts.—Mines which are so low as to afford no natural discharge of water, must be penetrated by shafts, and of course the mineral is then hoisted by means of machinery in these shafts. In sinking a temporary shaft, or a shaft of examination, the hoisting of the rubbish and water is done by the common hand-whim, such as is represented in fig. 43. These machines make labor expensive and should be avoided if possible; where a shallow pit of 20 or 30 feet in depth is to be excavated, its use is excusable, but if a greater depth is finally designed it is preferable to employ at once the horse-whim. In such shafts of preparatory work, water-tight buckets—kibbels—well secured by iron, are used, so as to contain gravel, fragments of rock, mud, and water at once.

The horse-whim and its application is represented in fig. 44. It consists of a vertical axle or shaft of strong wood, provided with radial arms for the horses to pull on. A drum upon which the rope winds is above, and generally from 3 to 5 feet in diameter. In mines where but little water enters, these machines are useful, for they may be made to lift a great deal of mineral, as the number of horses can be conveniently increased to four, or diminished to one. The class of horses and their time of work may also be altered, according to the demands of the mine. In all cases, however, where a large quantity of water enters the mine, these means are insufficient for working it to advantage. The power of one horse attached to these machines is easily calculated, when we consider that a strong horse cannot lift more than 5,000 pounds one foot high in one minute, inclusive of fric-

FIG. 43.

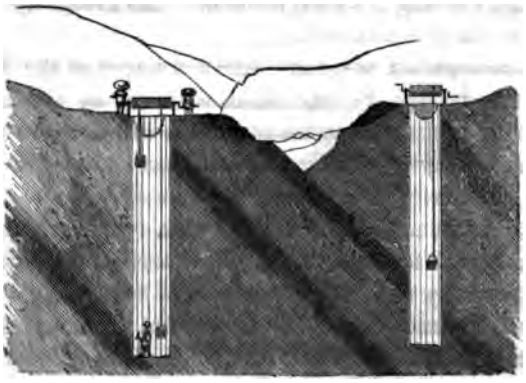
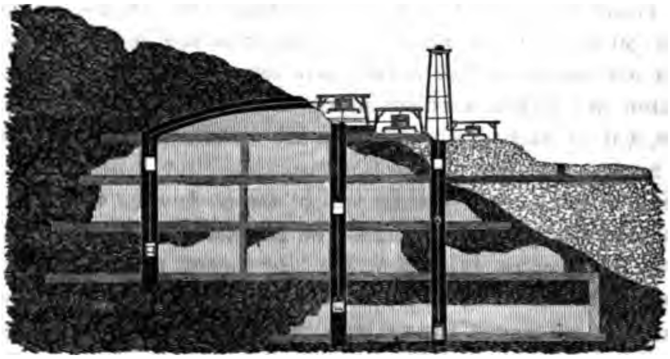


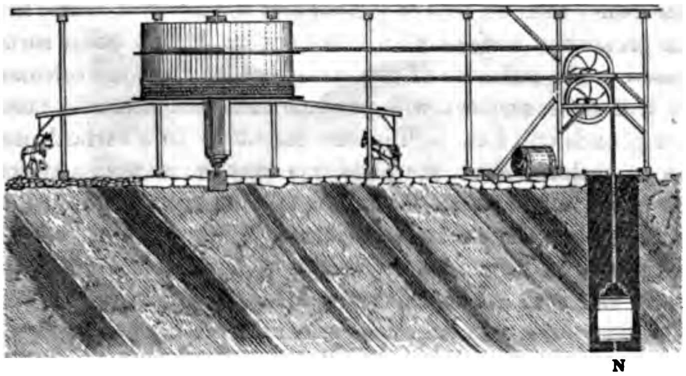
Fig 44.



tion. If we subtract from this the friction in the gudgeons, and the rigidity of the rope, the available effect of a horse amounts to not more than half of the above, and in most instances only to one-third.

In fig. 45 we furnish a drawing of a horse-whim, in general use at the mines in the Southern States, serving at the same time for hoisting minerals, and also for lifting water, which is generally so arranged that when ore is hoisted no water is drawn. Water is lifted in a large barrel, as shown in the drawing; this is a strong oak vessel well provided with iron hoops, and has a capacity of from 80 to 100 gallons; two horses generally are required to hoist it when filled with water. This water-cask is provided with a valve in its bottom, which opens when the vessel reaches the pool at the bottom of the pit, the cask then fills, and in reversing the direction of the horses N is raised. When N arrives at the mouth of the pit it is drawn over a drain, the valve opened, and the water flows off. While a filled barrel is thus hoisted an empty one is moving down, so that the horses are kept constantly at work. The minerals are kept in common kibbels, of which one is represented in the figure; these are about half the capacity of the water vessel, and in the form of a common bucket.

Fig. 45.



In mines from which a considerable quantity of mineral is to be removed, the hoisting is performed by a steam engine. The principle is in these cases the same, but as it is the object to hoist the largest quantity of mineral in a certain time, more attention is paid to perfect the machinery, so as to carry on the operation with dispatch. The power of an engine for drawing up minerals must be made proportionate to the vertical depth of the shaft and the quantity of mineral raised. One-horse power of the engine may lift 12,000 pounds one foot in one minute, after subtracting the friction in machinery, and in ropes or chains. The unit of power of a steam engine is not always a safe guide, for some manufacturers are inclined to overrate the power of their engines; and it may be advisable to depend in these cases more on the capacity of the boiler than on that of the engine; the latter of course must be in proportion to the boiler. One square foot of boiler surface exposed to the influence of the fire (whereby flues are calculated only half their surface), will produce sufficient steam for raising 1,000 pounds one foot high in one minute. In a vertical shaft, or in an inclined shaft, the platforms may move with a velocity of 10 or 12 feet per second. If we take these data it is easy to find how much labor may be performed by the engine; how wide a shaft is to be, for a certain quantity of mineral and water to be raised; and with what velocity this can be accomplished. The time used for the removal of the mineral from the platforms must be taken into account in making such calculations; and as the loss of time caused by these removals is a very important item, the means by which this removal is effected, are therefore, to be considered before concluding on a plan of machinery. Wagons which may be readily shoved on the platforms, and also readily removed, are the most perfect machines for facilitating the unloading of the platforms. Baskets, kibbels, or what is still worse, the use of kibbels without platforms, are instruments not at all calculated for mines in our country. Casks which are used for drawing water consume much time in being emptied by a small valve, and are not well calculated to facilitate the raising of water. It is necessary to lose as little time in reversing the motion of the hoisting power as possible; loaded wagons should be pushed off by the empty wagon, and the water-cask emptied while the horses are turned, or the engine reversed.

The engines, and the other means by which the platforms are hoisted are of various forms; in the main, however, they are similar, that is, a hoisting engine is always simple and compact, so as to be easily reversed and work equally perfect both ways. For these reasons high-pressure engines working full steam, and with a horizontal cylinder, are most generally applied, and in fact are the most useful. In fig. 46 we have shown an arrangement which is frequently applied with or without modifications. The fly-wheel is made smaller in diameter than is usual, and the engine with a short stroke so as to cause many revolutions in a certain time. The fly-wheel shaft is short and strong, to resist the effect of reversions with security to its parts. The pinion, which works in a large cog-wheel, and is fastened to the rope-barrel, or drum, is small in diameter and provided with strong cogs. One of the most important objects in these engines is the machinery for reversing; it must be quick-acting, and infallible. The means by which these reversions are accomplished are generally known to engineers, and there is no necessity of referring to any particular mode of doing them. The rope-barrel or drum, the form of which we shall mention hereafter, must be provided with a good axle of wrought-iron, cast-iron arms, and wooden covering, the latter when made of iron is rather severe on the ropes. A strong infallible brake at the rope-barrel is necessary in order to arrest the ascending load in case any thing goes wrong at the engine. The most common, and the safest brake is that represented in fig. 47. The lever A is fastened to a flexible belt of wrought-iron, which runs on a cast-iron pulley, and in fact surrounds it; on pressing this lever down, which is greatly assisted by its own

FIG. 46.

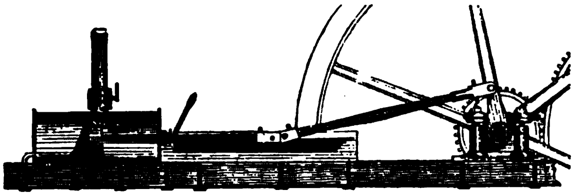
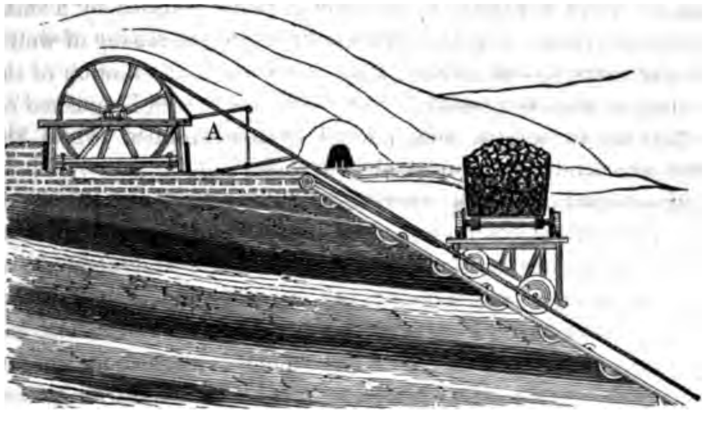


FIG. 47.



weight, the iron strap attaches itself closely to the pulley, and will arrest its motion. The pulley is firmly fastened to the circumference of the drum, and is in the middle of the length of the drum in case two ropes are used in hoisting. In some instances the brake is applied to the circumference of the fly-wheel of the engine; this is an imperfect mode of working it, for the cogs which connect the engine with the drum are more liable to break than any other part of the machinery; and if the cogs give way there is no method of arresting the load, the rapid descent of which may do incalculable damage to the mine, and to workmen; in this instance a little saving may cause much loss. The rope drum, the frame in which it rests, and the brake to it, must be infallible, and of extra strength, so that, if all other things give way, it will be safe.

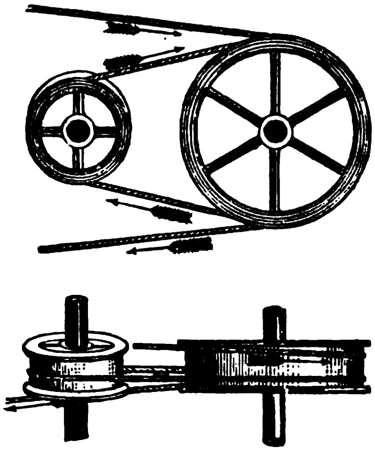
There are other means of hoisting besides those mentioned, but they are of limited use. Among them, is that by endless chains or ropes; it is impracticable in our mines. Another method is that applied at many iron smelting furnaces, where the descent of a cassoon, filled with water, raises the mineral from below. This mode of hoisting is only applicable where the mine is "level free," that is, kept dry by the natural drain of a level. It is slow in operation, and in this case a better effect of the water may be derived from a water-wheel erected in the mine. The cassoons are filled at the top of the pit, and are emptied by a self-acting valve at the level which drains off the water. In case the pit from which the minerals are hoisted is deeper than the draining level, the drum of the hoisting rope is made larger than that of the cassoon, so that the water descends slower than the mineral ascends. By these means, more effect may be obtained from the descending water.

In all cases, the mineral should be loaded in a wagon or a cart, at the stall of the miner, which should be pushed on the platform of the hoisting apparatus, and ascend, be taken off the platform and emptied, while an empty wagon is pushed on the platform. Shovelling, and the transportation of small loads, cause too much labor to be profitable in our mines. All that labor, which possibly can be done by steam, water or animal power, should be so done as to employ few men. Hauling and hoisting are some of the instances in which ingenuity may succeed in saving expenses. It is therefore advisable to make straight drifts, in case hauling is to be done, so that the power of the engine may be applied for hauling cars on such levels. It may be sometimes advantageous to enter a mine by an inclined shaft, in order to reach the centre, which could not be accomplished by a vertical shaft, and by that means apply the power of the engine to a longer distance than otherwise could be done.

Ropes and Chains.—Our mines are not commonly deep; we have few which penetrate more than 300 feet from the surface. We find, therefore, in most cases, hemp ropes employed for hoisting and transport. In a few instances we see chains or iron cables used, and in some mines wire-ropes. The kind of rope which is employed, and its strength, determines its durability and safety, and it is in so far an object to the miner to know the best means by which to hoist or transport minerals. Chains have been used, but they are found unsafe, heavy and expensive, and are most generally abandoned. The question is now between iron wire-rope and hemp-rope. In general, one pound of wire-rope is equal in strength to one pound of good hemp-rope; it is in most cases three times as strong, but there is no necessity of claiming more than pound for pound. One pound of hemp-rope will cost from 15 to 20 cents, and one pound of wire-rope from 12 to 15 cents, here is therefore the advantage in favor of the wire-rope. Hemp-rope is very unequal in quality; ropes of one and the same size may be, the one twice as strong as the other. This cannot happen in wire-ropes; the one quality of wire may be inferior in strength to another, but there cannot be so much fluctuation as is frequently found between hemp-ropes. There is another advantage of the wire-rope. Hemp-ropes are heavy, particularly when working in water and mud; they require more room than a wire-rope, and of course the machinery, particularly the drum, must be more capacious. As regards durability, we may state, that generally speaking a wire-rope will outlast six hemp-ropes, under common circumstances; but there are cases where the hemp-rope is superior in this respect to the wire-rope. In old coal-mines, or mines in which pyrites is decomposed, a large quantity of sulphuric acid is produced, which mingles with the water; this sulphuric acid is generally combined with some solid matter, such as clay or oxide of iron, and forms with these basic salts. These combinations of the acid do not hinder its corrosive action on iron. The acid will attack iron just as well as if it was entirely free to operate. Iron is thus rapidly corroded in coming in contact with such water, and in all cases where the waters of a mine are sour, the application of wire-ropes is not profitable, when the rope is to come in contact with that water. In all other instances wire-ropes are more durable than hemp. When hemp-ropes are found preferable they should be used in the form of flat belts; these are manufactured by laying two, three or more, left and right round ropes side by side, and holding them together by twine. These flat belts do not untwist, and are for these reasons more durable than round ropes. In the appendix we have furnished some tables showing the relative strength of chains, wire and hemp ropes.

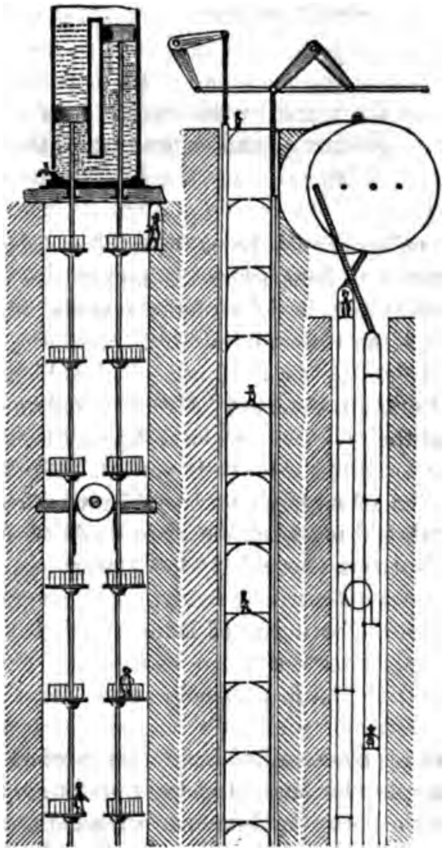
The drums upon which ropes are wound are most generally covered with wood, and there is no doubt wood is less severe on either a hemp or a wire rope, than metal. In some instances, cast-iron drums are applied, in which a shallow groove, in form of a screw-thread, is moulded, into which the rope is fitted. The latter plan is followed at the inclined planes of the Morris Canal, N. J.; the 3 inch diameter wire-rope winds upon a cast-iron drum of 10 feet diameter. In deep pits and long inclined planes, the drums should be tapered, so as to neutralize the gravity of the ropes in the pit. When flat belts are used instead of round ropes, the belt may wind one circumference upon the other; the drum assumes then the simple form of a flat pulley with high flanges. Wire-ropes do not occupy so much space in winding upon the drum as hemp-ropes; and for this reason, the machinery may be more compact. In some instances, the rope is only slung around a grooved pulley, and by the friction caused in the groove the rope adheres and lifts the load. This mode of winding and unwinding the rope is practised on inclined planes, as remarked in former pages. It is severe on the rope, for it acts at an acute angle, which causes the rope to be strongly compressed, and in most cases additional tension pulleys are needed to make the rope adhere. Wire-ropes used in this manner will not adhere so strongly to a grooved pulley as to lift the cars without artificial tension. This latter may be accomplished in the manner represented in fig. 48. The rope advancing in the direction of the arrows, is slung around the large drum or flat pulley; it is then led upon the small pulley, around this, on the large pulley again; and may now be led off the drum; or the process may be repeated once more; and, in fact, until the required friction of the rope is produced. The axis of the small or loose pulley is inclined to the axis of the large pulley, and when the rope leaves the small pulley, the latter directs it one thickness farther, so that no friction of the rope may be caused. In all instances where wire-ropes are used, the pulley should be at least of so large a diameter, that when the iron is bent around it, no permanent bend in the iron is produced; the elasticity of the material must never be taxed too high, if we expect durability.

FIG. 48.



Descent and Ascent of the Workmen.—This subject is frequently less attended to than it deserves. Men have only a certain quantity of power at their disposal; when that power is exhausted their work must necessarily cease, or be imperfect. Working in a mine causes exhaustion of strength sooner than working in the open air; and men should not work longer in a mine than eight hours at a time: this refers particularly to damp mines, and those in which the air does not circulate freely. The common method of descending a shaft is by means of ladders; this is tedious, and a man's power is almost spent when he descends or ascends four hundred or five hundred feet. In deeper mines, the exhaustion of power is still greater, and we should not expect much work from a man who is over-exerted before he reaches the place of his labor. In other instances, flights of stairs are provided, on which the labor of ascent and descent is less tedious, but is equally difficult. Our mines are not generally deep, but those of 300 and 400 feet in depth require some exertion on the part of the workmen to enter and leave the mine. This operation is frequently performed by the workmen who step on the platform, or in the buckets, and are thus hoisted or sunk by the engine. This is dangerous; and a man who desires to save his life or limbs is not inclined to make use of these means; chains and ropes may and will break, or a bucket or platform is often disturbed by the guides, or by the timber or rough walls of the shaft; and in all these instances, the unfortunate laborer is precipitated to the bottom of the pit, injured, perhaps in the slightest case, for his lifetime. For ascent and descent no apparatus is more suitable in our country than that which is contrived in some of the German mines, and is now also employed in some of the English mines. It is represented in fig. 49, which shows two

FIG. 49.



different modes. In all cases, two rods descend the whole length of the shaft, which may be of wood or iron; the first material, however, appears to be preferable. In order to secure the safety of the men, in case any part of the machinery should break, balance pulleys are fastened at certain distances, over which a chain is slung which balances the weight of that part of the rod below the pulley, and in case one side of the machine is injured by breakage, it will be moved by the other side, and no interruption of the regular motion will happen; the men are therefore perfectly safe. These balance pulleys may be in distances of a timber's length, say from 50 to 60 feet. To the rods platforms are fastened, so that one or two men may stand on each: these platforms are from 10 to 20 feet apart, to which the lift of the rod corresponds. The opposite platforms meet at the dead points of the up and down motion, and at this culmination the men step from one platform over to the other, and by this motion from one side to the opposite they may either ascend or descend, as they choose. The meeting of the platforms being at the dead points of the cranks, there is a short rest in the motion of the rods, and the change of place may be accomplished with perfect safety by the men. The motion of these rods may be accomplished by means of cog-wheels, as is shown in one part of the figure, or by means of cranks or levers, as in the other; or by water directly, as shown in the third figure.

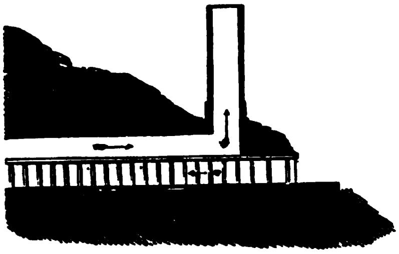
The rods may in the mean time serve as pump-rods, driving a set of pumps at the bottom of the pit, or a system of pumps at various heights. They may also be employed for forcing fresh air into the mine, and extracting foul air. In case iron-rods are used, two rods are necessary for each flight of platforms; the latter is then fastened between the two rods.

CHAPTER VI.

Ventilation of Mines.—The interior of a mine is never provided with air as fresh and good for respiration, as that above the surface of the earth. When men penetrate the earth by narrow, and particularly newly-made passages, their own respiration, added to that of the combustion of candles or lamps, the use of gunpowder, and the decomposition of minerals, very soon vitiates the air in these subterranean vaults. There are a multitude of causes which impair the action of the lungs, and by that means the vital action of the whole body. If we expect a man to work, we must supply him by all means with the necessary elements of life; and as fresh air is as much a requisite as food, we must furnish the latter by artificial means in case the natural forces are inadequate for that supply. Rocks that are naturally dry, such as volcanic and primitive rocks, which are liable to decomposition, do not often interfere with the health of the miner; but minerals which decompose by friction or on being crushed—such as sulphurets, pyrites, mineral coal, decaying wood and timber; fissures which liberate carbonic acid, hydrogen, or sulphuretted waters; the penetration of surface water, carrying along with it decomposed animal and vegetable matter—all these causes vitiate the inclosed air, and hence the necessity of maintaining in mines a continual circulation, which may renew the atmosphere around the miners. The means by which this object is accomplished constitutes the art of ventilating mines.

Natural Means.—The means by which the ventilation of a mine is accomplished, may be divided into two classes—natural means, and artificial means—both are, however, more or less artificial; the first employs no machinery, while the latter causes the motion of air by some artificial power, either water, or steam, or muscular power. The temperature of the air in a mine surpasses always the mean temperature of the place at the surface; hence it is lighter in winter, and heavier in summer, than the air of the atmosphere. If a mine is provided with two shafts, or two entrances, and both are at a level, there will always be a slow motion in the air of the mine, caused by a tendency of the atmosphere to enter the mine when a difference of temperature exists between it and the mine. This motion is even perceptible if the air inside and outside of the mine is of a different composition; but it is so faint as to be of little service in ventilation. If the temperature and composition are similar inside and outside, no motion can ensue; this happens to be the case in the autumn and spring seasons, and in stormy weather. When the air is warmer outside than inside, no motion of air exists in the mine; this is the case in summer, and in warm climates. For these reasons, preparatory works, which cannot be ventilated, should be done in the winter season; the air of the mine is then lighter than that of the atmosphere, and a faint circulation, sufficient for a few hands, is produced by this cause. In most of these instances, the circulation is insufficient for a number of workmen, particularly where the quality of air is impaired by causes existing in the mine itself, and we are compelled to employ artificial means in order to secure circulation. When the mine presents two openings at different levels, the air will flow out by the most elevated in winter, and by the lowest in summer. The greater difference there is in the height of these openings, the more rapid the motion of the air will be. The same principle is acting here which produces the draft in chimneys. By these means we may succeed in supplying fresh air to all parts of the mine. The positions of the two openings of a mine must be so located that the greatest difference in their level will be obtained, and that they may be at the opposite extremities of the mineral deposit. We have endeavored to show this in previous pages. When no such means as different heights of openings, or even a second opening, can be obtained, we may produce circulation to the farthest end of a mine by a spacious drift. The drift, fig. 50, is made high, so that the lower part is smaller than the upper part; both are divided by a board partition. The fresh air, which enters into the lower part, is conducted to the work-rooms; and through these into the upper part of the drift, in which it returns, and is drawn out either by a chimney or a shaft. The difference of temperature in the two compartments of the drift is sufficient to produce circulation; and when the partition is tight, and the mouth of the upper part elevated by a chimney, it produces even a strong draft. In these instances, the waters of a mine are of great service for ventilation, particularly if these waters are in motion, dripping down the rocks, or falling over

FIG. 50.

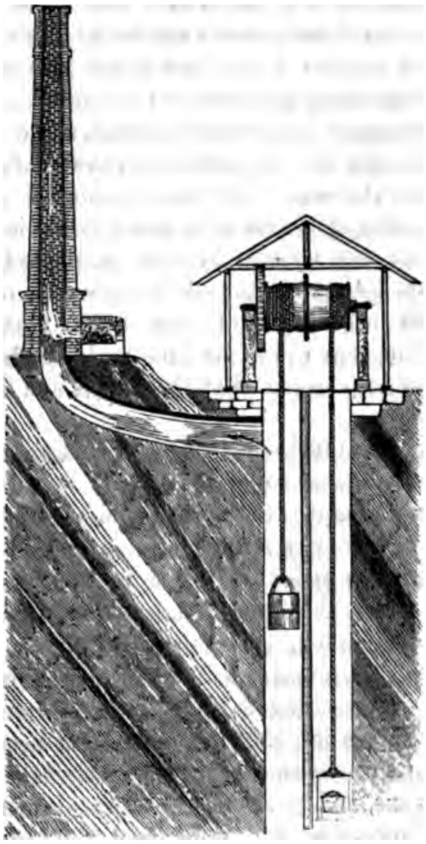


precipices so as to form spray. The vapors thus produced are lighter than air and ascend rapidly, forcing air along in their motion. The water being thus cooled by evaporation, cools in its motion the rock over which it flows, and also the air which may come in contact with the rock. The mine is thus cooled, and warm air may enter freely in the lower part of the drift; the upper part will be always more warm and the air more diluted than in either the mine, the drift, or the atmosphere.

All these natural systems of ventilation are frequently disturbed by atmospheric influence—the changes indicated by the barometer affect the mine; cool days in summer, and warm days in winter, are often the cause of suspending the work for want of air. Stormy weather always disturbs such natural ventilation. In all cases where two openings at the extremes of the mine can be procured, it is the preferable plan ; and if the difference of level is not sufficient to produce the required draft, a chimney may be erected over one of the pits in order to increase the difference in level.

Artificial means.—When natural means fail to be sufficient for the circulation of air in a mine, it must be produced by artificial means. The most simple plan is the division of the drift, which is in small mines often more or less complicated in form, but in principle always the same. When a shaft is used instead of a drift, it is divided by a partition into two compartments, one of which is provided with a tower and wind-tube, to carry fresh air down. Such arrangements are, however, imperfect, because the mine is thus compelled to depend on the currents in the atmosphere for a supply of air. The more common method is to lead a horizontal channel from one of the compartments of the shaft, so far as is necessary to make the erection of a chimney safe. In a divided shaft no such difference of temperature is produced as that in a divided drift, and the mere erection of a chimney over one part of the shaft, would not cause much circulation of air. In this instance a sufficient supply can hardly be effected without an artificial draft in the chimney, which is made by fire, or other means. Then the arrangement assumes a form as represented in fig. 51. In the chimney a fire is kept at those times when the natural circulation of the mine is not sufficient to supply the required amount of air; and if a large quantity of air is required, a constant fire must be kept up. In some instances, the foul air from the mine is led through the furnace, so as to burn its combustible parts, but in most cases the furnace is separated from the channel which conducts the air from the mine to the chimney. In all cases where two openings lead to the mine, it may be a divided shaft, or a second shaft. The draft in the mine is increased by the erection of a chimney and the addition of a furnace and fire. In some instances the fire is kindled in the mine itself, and the upcast shaft receives the heat. This is a bad step when the shaft is not properly constructed and prepared for the purpose; the smoke and foul gas instead of escaping often returning into the mine and causing more evil than good. The air in being passed through burning wood or coal is converted, in great part, into carbonic acid; this is heavy, and when cooled in its ascent will return to the mine, because it is heavier than the at-

Fig. 51.



mospheric air. Any application of fire in a mine, when not necessarily connected with the operation of mining itself, is to be avoided, for it is never advantageous. If hot steam, or hot air could be conducted into an upcast shaft in pipes, so as not to change the composition of the air as it issues from the mine, or if merely heat is added to it, so as to make it lighter and have more tendency to ascend, this would be a better plan than either the application of fire above ground or in the mine. At most shafts high pressure steam engines are in operation, and were the exhausted steam conducted through pipes down the shaft, so as to heat the ascending air, the current in the mine would be greatly augmented. When the pipe leading the steam down is so long as to condense all the steam made by the engine, and its lower end reaches at least 30 or. 40 feet downwards and terminates in a tub of water, so as to keep the air out of the exhaust pipe, a condensation of the steam will be produced, which enhances the labor of the engine, saves fuel at the boiler, and is a benefit to the mine.

When the heat is not sufficient to produce the required draft, machines are used either to force fresh air into the mine, or extract the foul air from it. Both systems show peculiar advantages in their application. For forcing air into a mine, the common centrifugal blower is undoubtedly the most preferable machine of those in use; and as the form of these blowers vary, we present in the annexed figure 52, one of the most perfect models of this machine. The illustration shows two sections vertically through the machine. The casing to the revolving vanes is cast-iron, which is best shown in fig. 53; it is screwed together, and consists of two parts or shells. The axle, made of steel, rests at both ends on gudgeons, and pans of steel or anti-friction metal. At one end the axle carries a pulley of from 4 to 6 inches in diameter, on which the strap runs which drives the vanes. Upon the middle of the axle a wrought-iron cross is fastened, which must be as light as possible, and of uniform weight in its parts, so that, when the four arms are of equal length and form, the axle is in every position at rest when turned round in the points of the turning lathe. To these four arms, four wings, blades or vanes, as they may be called, are fastened; these are a little curved, and their convex sides are turned in the direction of the motion. The blades or vanes are made of sheet copper, and are of equal weight and size. They are riveted and soldered to two light copper shells, which, having the diameter of the largest circumference of the vanes, form a casing inclosing the vanes, arms and axle. These parts compose one piece. The cast-iron casing has two central openings, one on each side, into which the air enters. The air is then whirled round by the vanes, and a centrifugal force imparted which causes it to escape with pressure at the periphery of the casing. The chief loss of power in a common fan-blower is between the vanes and the casing; for this reason, a second casing is here applied and fastened air-tight to the vanes. This casing, of thin sheet copper, revolves with the axle and the vanes, and its centre is provided with openings as large as those in the exterior cast-iron casing. If both openings are well turned, so as to run closely, not much air can escape at these centres. A perfectly close fitting joint cannot be made, but it is easy to make one here more perfect than at the extremity of the vanes. The dimensions of these machines vary according to the quantity of air required. A blower of 3 feet diameter, with square blades of 6 inches, and making 700 revolutions, will produce about 800 or 900 cubic feet of air per minute. The quantity of air furnished by a fan depends very much on the capacity of the discharge. If the latter is small, not much air is furnished but the pressure is stronger; and on the contrary, if the nozzle, or blow-pipe, is larger than one of the vanes, little pressure but much air is produced. In all cases, the opening for discharge should not be

Fig. 52.

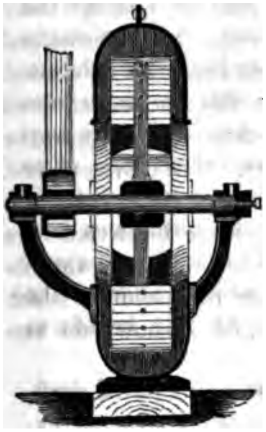
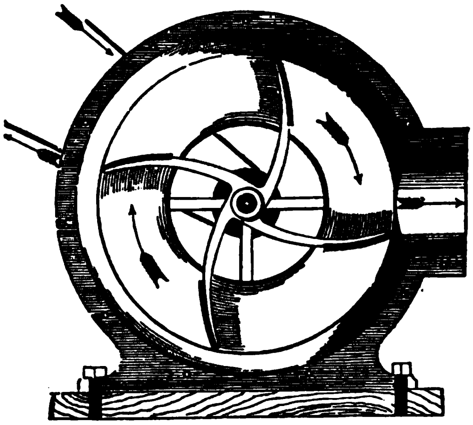


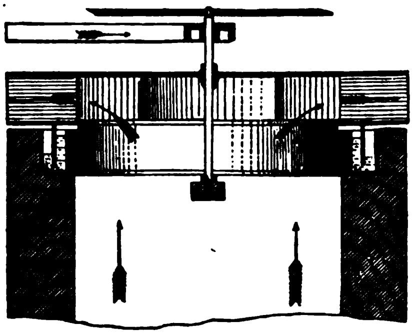
Fig. 53.



smaller than the area of one of the vanes. If it is much smaller, it causes a loss of power by friction but no loss in pressure.

In mines, not much pressure is required to drive the air through the galleries and rooms; for this reason the above fan can be provided with large openings for the air, and also distribute it freely as it arrives at the periphery of the vanes. The air in mines is in summer generally heavier than the external air, and in winter lighter: and as the motion of the air is produced by centrifugal force, and its specific gravity is an important item, the air should be as heavy as possible, in order to obtain the greatest effect of the machine. It is therefore advisable to force the air into the mine in summer, and suck it in during winter. The blower should be arranged to connect the centres, or openings, either with the mine or with the atmosphere. There are some inconveniences connected with the above described fan for accomplishing this object; we present, therefore, other drawings of machines which are more suitable for this purpose. In fig. 54, is shown the vertical section of a fan which may be laid over the mouth of the pit, or some convenient place near the pit. The vanes which are here fastened to a round bottom or shell, throw the air at the periphery directly into the free atmosphere, or into a channel leading to the mine, as the case may be. In order to prevent leakage, a collar is fastened to the rim of the wheel at its lower side, and this dips into a circular trough of water, which causes a perfectly air-tight packing. The friction of the collar in the water is very small, provided it is perfectly round and smooth. In fig. 55, a section of this fan-wheel is shown which indicates the form of the vanes, and the size of the rim in proportion to the centre and the large diameter. This machine affords a large passage for air.

Fig. 54.



It is not so well adapted as fig. 56 for producing pressure, but evidently superior in respect to furnishing quantity, which in this case is of more importance than pressure.

FIG. 55.

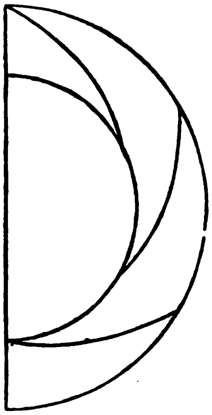
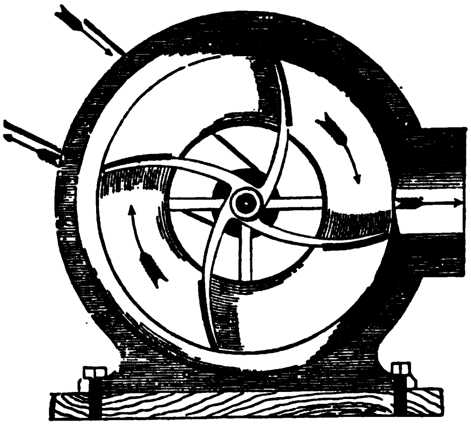
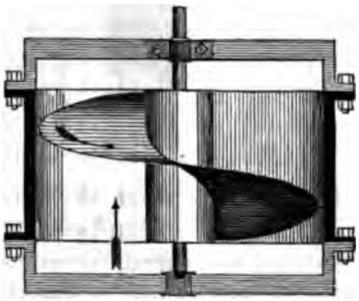


FIG. 56.



In fig. 57, we represent still another form of exhauster, or as it may be called, compresser of air. It is also a cast-iron cylinder, firmly set in a wall, in either a vertical or a horizontal position. In this cylinder an axis moves, which is in the axis of the cylinder, and to this a spiral is fastened which is made of sheet-copper. In revolving the axis, the screw will draw air into the cylinder in the direction of its progressing motion. This machine, when placed in any position, will either draw the air from the pit, or force fresh air into it, merely by rotating it in the one or the other direction. A common smoke-jack, or a machine in that form, may be used for the same purpose; but all these machines never furnish as much air, by the application of the same power, as the above-mentioned fans.

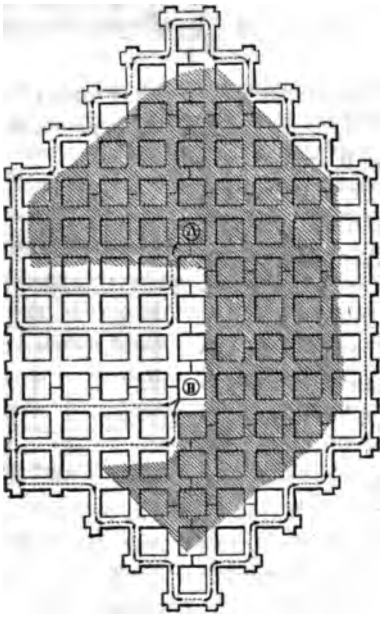
FIG. 57.



Various other forms of machines for ventilating mines have been proposed and are in use; but all are more complicated and more expensive, and of less practical effect than those above mentioned. We abstain, therefore, from describing any of them. Fans, or Archimedean screws, are easily constructed, easily kept in repair, and a small horizontal steam-engine is readily connected with them for putting the machine in motion. Where water-power is at command, a small turbine or reaction-wheel, which furnishes a great number of revolutions, is the most convenient form of applying it.

Distribution of Air in the Mine.—The form and size of the channels through which the air passes in a mine, are of the utmost importance to its ventilation. Most of the accidents which happen are more generally caused by imperfect circulation than by want of fresh air. In our country the mines generally are of so recent date, and so high above the water levels, as to cause no serious apprehensions of danger from explosions; the gradual extension of our mines, however, will soon bring the subject to the notice of the public. A recent explosion in a Virginia coal-mine, whereby eight men lost their lives, is an indication that our mines are not excepted from the production of explosive air.

Fig 58



In fig. 58, we represent the mode of circulating air in an extensive mine. In this fig., B represents the downcast shaft into which the fresh air enters. It is made to circulate all over the mine, and enter the upcast shaft after having passed throughout the whole extent of the mine—the workrooms, and those dead workings in which inflammable gases are generated. These vitiated gases are not permitted to accumulate in abandoned workings, and spread over the mine on a favorable opportunity. By means of doors the current is directed first of all over the workplaces, and from them to those which may generate explosive gas. By pursuing the track of the arrows we find that the workmen are near the air-pit; and as they take out the passages, the air is made to course first near their work, sweeping along the wall faces of their rooms, and is thence conducted through those passages which have been left for future operations. The stoppage near the downcast shaft is therefore permanent; if it was removed all circulation would cease. The stoppage between the new rooms and the old rooms is moved with the advance of the men, or new doors are put in. In all cases the air must circulate throughout all the galleries and rooms, so that no dead place is omitted and no partial stagnation can happen, which inevitably will produce explosive gas when it mixes with fresh air. The permanent stoppings are therefore firmly secured, not only by wooden doors, which may happen to be neglected, but are walled up with stones or brick, forming a permanent solid partition. When these main stoppings are well put in and firmly secured, they afford the additional advantage of security to the workmen. If an explosion happens in a remote part of the mine, the men near the main stoppages are either not affected by it, or are at least more safe, than when these are broken by the force of the explosion. The principle involved in these arrangements, is to dilute the obnoxious air in the mine so much, that the portion of bad air is never sufficient to injure the health of the workmen. As the fresh air from the entrance, or downcast pit, is first distributed to the workmen, it may happen that under certain conditions of the atmosphere a large quantity of bad gas is produced, which, if it is in a coal-mine, is generally inflammable gas; and those men whose duty it is to watch the circulation, should be cautious in advancing with exposed candles to the old workings. When the quantity of firedamp in a coal-mine increases to an unreasonable degree, which is indicated by the flame of the candle, it is advisable to suspend operations until sufficient fresh air has been forced into the mine to dilute the dangerous gas. Most of these gases are generated in stormy weather: when the barometer is sinking a larger quantity of bad air is liberated than when it is constant or rising. Warm air, also, is more productive of noxious gases than cold air; for this reason, a mine is in better condition in winter than in summer. In all cases the coldest air should be introduced into the mine, if there is an opportunity for it. Dry air is of more service than damp air; it will absorb moisture from the mine, and by that means cool the interior.

Quantity of Air.—It is difficult to estimate the quantity of fresh air required to ventilate a mine. This is a practical operation, depending entirely on the extension of the mine, the kind of mineral, and the form of the passages. In all cases, it is of advantage to introduce an excess of fresh air, and in a judicious manner, so as to bring it to every part of the mine. In winter seasons there is a natural tendency of the air to rise from the pit's mouth, but it is the reverse in summer; and as the air during summer is more rarefied and contains more moisture, it is also more liable to produce decomposition; particular attention is required at these times to furnish a sufficient supply, and if an excess is ever needed it is at these seasons, and when the barometer is sinking. A mine may indicate a liberal supply of air, both at the workrooms and at the air-shaft, but it does not follow from this that it is safe. If the fresh air does not penetrate the old rooms, where decomposition of mineral is going on and constantly increasing the dangerous gas, it will break forth some time, stop the circulation entirely, and endanger the lives of those who depend on the access of fresh air. The quantity of fresh air introduced into a mine is no guaranty of its safety; it is the manner of its distribution which forms the essential condition. There may be ten times as much air introduced into a mine as is actually necessary, and still a mine may be dangerous for want of fresh air. Moist and warm air is peculiarly apt to decompose minerals. It decomposes sulphurets most readily; and, when the temperature of a mine is high, it will produce sulphurous acid; if the mine is cool it forms chiefly sulphuric acid, which is not obnoxious, and is readily carried away by the waters of the mine. Damp air is more quickly decomposed than dry air; and carbon, sulphur, hydrogen, and low oxidized metals will absorb its oxygen, and impair its quality for respiration. A less quantity of dry air is therefore of infinitely more service in a mine than a large quantity of damp air. The particles of one kind of matter readily mix with those of another kind when at liberty to move; this is particularly observable in gases; when therefore air is introduced into a mine, the quantity of foreign gas which may be absorbed by it, will chiefly depend on the amount of air brought into the mine, and what is particularly important, on the manner in which it is brought in contact with the gas which is to be removed. If the fresh air is not brought in contact with the obnoxious gas, it will not absorb it, or at least very slowly. The kind of gas which is to be removed has also some influence; if the affinity is great between it and the air, a larger portion of the first is absorbed by the latter than when the affinity is weak. In all cases there is sufficient affinity to remove any kind of gas by atmospheric air; the quantity required, however, may be more or less. Carbonic acid mixes with air to a limited extent; the latter when in motion will carry it away. Moist air will absorb more carbonic acid than dry air; if therefore carbonic acid gas is to be removed from a mine, a small quantity but a strong current is required to move it. Sulphurous acid gas is removed under the same conditions as carbonic acid. All mines, except those of coal, produce heavy gases, which require a strong draft to carry them away; it is therefore advantageous in such mines to limit the quantity of fresh air to the smallest amount, and keep that in lively motion. In coal mines the case is different, the bulk of the gas in them is carburetted hydrogen; its affinity for atmospheric air is great, but it requires a large quantity to neutralize its bad effects. When atmospheric air is mixed with hydrogen, or still worse, carburetted hydrogen, to a certain amount, it forms an explosive mixture; that is, if a spark of fire touches one particle of that air it will ignite it, and the heat generated is sufficient to kindle the next particle, which spreads so rapidly as to ignite large volumes of such gas in an instant. The product of this combustion is an intensely hot vapor and carbonic acid gas, which in its tendency to expand will overthrow and destroy every obstacle in its progress. In coal mines sufficient fresh air must be introduced to prevent the formation of the explosive mixture. While the atoms of the carburetted hydrogen are so far apart as not to ignite each other, there is no danger of an explosion. In such cases a large quantity of air is required to carry off the inflammable gases. It is not so much needed for respiration, as men may live and candles burn in an explosive mixture of gas. It is, therefore, not possible to determine the amount of air which may be required in a mine previous to working it; if, while in operation, we find the atmospheric air is deficient, we introduce more by some means.

Old mines are most liable to generate large quantities of bad air; it is therefore advisable to shut up those parts which are not in use. An imperfect separation from the workings by means of wooden doors, or partitions, by dry walls, or open piles of rubbish, is a bad practice. It may be preferable to leave the works altogether open, and continue the supervision and ventilation of them. In most instances it may be expensive to close up old works; it is, however, necessary. There is no safety in an old coal mine, with dead workings, because the stagnant gases pervade the whole of the abandoned spaces, and when the pressure of the atmosphere diminishes, which is indicated by the sinking barometer, it will rush forth and cause destruction. It is therefore plain, that all old mines must be hermetically sealed by strong walls, or kept open entirely, and be properly ventilated.

Form and Dimensions of Air-Passages. — This is a subject frequently neglected by miners. Men who do not reflect, will open an air passage, little thinking that it may be either too small or too large. A passage is too small if it does not admit sufficient air to purify that part of the mine which it is to supply. An air passage is too large when it passes more air to its part of the mine than is required, and deprives other parts of the necessary quantity. If, on inspecting the mine, it is found that some parts of it are ill ventilated, it is necessary to increase the size of the passages and admit more air. If their dimensions cannot be increased, then the force of the draft must be, in order to obtain more fresh air. In all instances, as it produces the same result, we may widen the channels which conduct the air, or force the air in and through the passages with greater velocity. The natural means by which we produce circulation are at best faint forces, and it requires spacious passages to conduct a large quantity of slow-moving air. It is therefore advisable to make all passages for air as wide and spacious as circumstances will admit. There is never any harm in making the passages too large; but there may be incalculable loss of life and property if they are too narrow. In all cases a passage too wide is readily made narrower by a partial partition, or by a permanent stone wall with the proper openings. Wide passages afford the advantage of leading the current of fresh air into the most dangerous parts of the mine, by applying divisions in proper places. The partitions may also be made to lead the current of air along the roof or the pavement of the mine; in the latter case, by raising the partition above the floor and closing the passage at the roof, and by closing the partition at the bottom and leaving it open at the top, the current is drawn along the roof. The first plan is adopted where heavy gases are to be removed, such as carbonic acid, sulphurous acid, and similar compounds; the current of air should pass along the roof when carburetted hydrogen, or hydrogen and its compounds, form the obnoxious gas.

The movement of air in a mine is effected on the same principles as that of gases or fluids in pipes; we are therefore to make the passages as wide as possible in order to diminish friction, and we must avoid short bends and sharp angles, and also irregular contractions as well as rough walls. All obstacles to motion require either additional force, or cause a diminution of effect; that is, the quantity of air which passes through the mine is diminished in consequence of the obstructions to its motion. We may always supply the requisite quantity of air for the ventilation of a mine, but it demands a power which increases with the cube of the air needed; the resistance to the motion of gases increases in that ratio. It is therefore preferable, in all instances, to make the air passages too large rather than too narrow; and this will apply to drifts and shafts as well as to galleries. There is no excuse for allowing bad air to remain in a mine; if such is the case, it arises either from ill-management or avariciousness; if the passages are too narrow, the power of a steam-engine or that of a water-wheel may be used in forcing air into the mine; and if dead workings are not properly ventilated, it is because the means of ventilation are insufficient or injudiciously applied. All cases of accidents in mines, caused by bad air, should be made criminal offences by law, and the owners rendered liable in damages to the families or heirs at law of the deceased or the crippled. Explosions in mines are never caused by the fault of the workmen; for if a sufficient supply of fresh air is forced into the mine, and that well distributed, there cannot be an explosion.

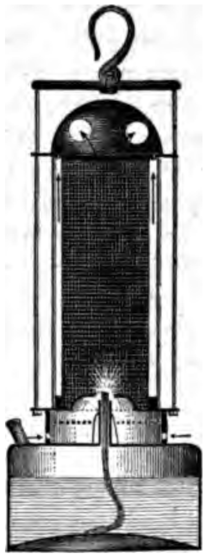
Safety Lamp.—The miner, in searching within the crust of the earth for the riches which it conceals, is exposed to many dangers. The rocks in which he digs are seldom entire, and the impending fragments threaten to fall and crush him. Atmospheric air follows him in those often intricate passages with difficulty, and the waters issuing from the rocks annoy him—he must provide for their removal, or be exposed to drowning if he permits the accumulation of them. Of all dangers, the explosion from the accumulation of firedamp is the most disastrous. Such a catastrophe in an extensive coal-mine is horrible in the extreme. A mine is at one moment full of life, cheerfulness and animation; the clink of the miners' tools resounds throughout the subterranean vaults; carriages on railroads passing to and from the workmen enliven the scenes of the dark recesses; happiness and alacrity are pleasingly contrasted with the surrounding gloom; but the next moment may bring desolation and death to all. The firedamp accumulated in a part of the mine is set in motion; it mingles with the slow current of fresh air to the point of an explosive mixture, when the unsuspecting miner brings his candle in contact with it, and sets the whole interior of the mine in a blaze of burning air. The ignition of such a mass is instantaneous. Immediately it suffocates and scorches to death every living creature within reach; those beyond the reach of the flame are dashed down by the force of the explosion, and the irresistible body of hot air which rolls along the winding galleries; the mouths of pits and passages are converted into the flaming throats of a volcano, casting forth dust and stones, wheelbarrows and men, and hurling heavy wagons high up into the air; the earth trembles by the force of this gigantic power, and the machinery at the entrances is generally destroyed. No wonder miners are pious to superstition, when their intellects cannot comprehend the cause of the awful destruction set in motion by an apparently innocent spark of fire. Wise and good men, observing the destruction of human life in such cases, have taxed their minds for the invention of preventives, but these benevolent exertions merely increased the avarice of men—ventilation is now more neglected than before the invention of Davy's safety-lamp, and explosions are more frequent than ever.

We should not allude to the safety-lamp of Sir Humphrey

Davy if it was not wanted for the examination of a mine. The workman should never use it; there should be always sufficient fresh air in the workrooms and galleries of the mine to render open lamps or candles perfectly safe. Any mine, particularly a coal mine, requires frequent inspection by the foreman or superintendent. This should be made at least once a week. The remote passages for air and water should be inspected, timber and walls examined, and also the composition of the air. For this purpose a safety-lamp may be necessary in some instances, particularly in old, extensive coal-mines, and those which furnish coal of easy decomposition, such as the bituminous coal of Virginia, some in Ohio and Illinois, Maryland and Nova Scotia.

In fig. 59, we represent an improved safety-lamp, on Davy's principle, which affords more security and light than the simple wire-gauze lamp. The common Davy lamp is a round vessel of oil with a wick in its centre, the flame being covered with a cylinder of wire-gauze, of about 2 inches in diameter, and from 6 to 8 inches high, tapering towards its top. This simple form of lamp is not quite safe, for if the air is very inflammable the wire gets heated, and will pass the flame through it, particularly when the lamp is moved. Instead of one layer of wire-gauze two have been used, but even these were not found secure. The improvement represented in the cut is a simple Davy lamp, with only one coat of wire-gauze, in order to diminish the light of the flame as little as possible, because one of the objections to these lamps is their diminishing the light of the flame. The wire-gauze is in this case surrounded by a glass cylinder, and the air for feeding the flame passes in below the cylinder only, through a range of holes bored in the oil vessel. The air passes next through one or more disks of wire-gauze which are fastened above these holes, below the flame or wick. It then passes a small cupola of a brass disk which has a little orifice in its vertex, so that explosive gas is forced to the flame and must burn. The wire-gauze disks, below the flame and the cupola, are for the prevention of a returning motion of the inflamed gas through the lower parts of the lamp. The gas

FIG. 59.



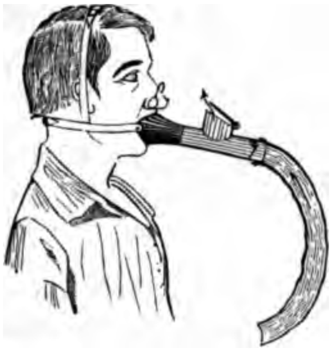
being thus completely burned before it reaches the surrounding cylinder of wire-gauze, cannot extend to the surrounding air. The access of more air to the wick than the wire cylinder can conduct, is prevented by the small holes in the bottom of the lamp and the glass cylinder; this hinders the lamp from getting filled with flame, which is the case when only a simple coat of wire surrounds the flame. The glass cylinder is held down by a brass cupola, which is provided with some holes for the escape of the hot and burnt gas. The lamp is surrounded by a number of vertical wires, which serve to protect the glass against injury, and in case it should break by accident, the lamp is still a common Davy.

Trying the Air.—The state in which the air of a mine is, may be tried by the flame of a candle. It is rather a delicate operation, and requires some experience to perform it satisfactorily. When there is a mere defect of oxygen in the air, it having been partly consumed by the respiration of the workmen, or the decomposition of the minerals, the light burns with a dull reddish flame, the tallow gets hard and ceases to supply the wick abundantly, and if the state of the air is very bad, the flame flickers and dies gradually away. In this case, the candle may be kept burning by inclining it, which causes the tallow to melt and supply the flame. In all instances of such trials the wick must be clean, free from snuff, and trimmed to a point, so as to produce a clear, distinct flame. When nitrogen abounds, the flame is long and yellow at the top, and often brown,—the clear flame being very short and dim. When carbonic acid abounds, the flame gets smaller by lowering the light towards the pavement. If the light burns dim, or expires, it is time for the miners to retire, and more fresh air must he introduced. Heavy gases are, therefore, never dangerous, and it is the miner's fault if he suffers from the effects of such bad air, for he finds out, by a safe and infallible experiment, whether he can live and work in the mine or not; for if the candle does not burn clear in an ore mine, the miner has no business there.

Coal mines differ in respect to the quality of the air from those of other minerals; for a candle may burn, if not perfectly, at least sufficiently clear for work, and the air yet be vitiated to the explosive pitch by firedamp. When an inflammable air is supposed to be in a mine, the miner trims his candle well, taking off the snuff as close as possible with his fingers, so as to produce a pointed wick; he then advances with cautious steps, holding the candle in the left hand, screening it with the right. If he finds, in his progress, that the flame in his natural position burns dim at the tip, he lowers it cautiously. If the flame burns red near the pavement, there is choke damp, or carbonic acid in the mine. He endeavors now to carry the candle so high as to be above the heavy gas. Carburetted hydrogen of the mines is lighter than atmospheric air, and floats near the roof, the miner must therefore be cautious in raising the candle too high. He should hold it close and steady before him, with his eye fixed on the top of the flame as he moves forward. If, in his advance, he perceives the tip of the flame elongate; that is, if the clear flame gets shorter and the elongation assumes a grayish-blue color, he must be on his guard. If he holds his candle low at the time, and it shows indications of firedamp, he must not raise it higher, for at the roof the mixture may be explosive when it is not so near the pavement. When the tip of the flame begins to spire, he should stop from farther progress, lower his candle, and either retire, or if his object is to examine the gas, drop down on his knees, holding the candle near the pavement. On raising the candle gradually, he watches the change which the flame may undergo as he approaches the roof with it. If the inflammable gas is copious in the mine, the flame elongates into a sharp spire, the dark top of the flame also elongates; so far there is no danger of explosion. But if the tip of the flame, in raising the candle, changes from the bluish-gray to a fine blue color, and burns like sulphur, and frequent small bright specks are visible in the blue top of the flame, it is dangerous to advance any farther, and equally dangerous to retreat. The miner, provided he knows his way back, suddenly extinguishes his candle, which is easily performed, as the right hand has been always close to the flame; or he endeavors to retreat with the candle, which must be done cautiously and without much motion; for a sudden movement of his body may mingle the gases and cause ignition. If the miner ventures any farther with his candle, when the air is in this condition, the flame will at some spot suddenly elongate and set the whole mine in a blaze. There is, however, so much practical knowledge required, and the locality has so much influence on the form and top of the flame, that rules upon which a miner may depend with safety, respecting the form of the flame of the candle, cannot be given.

Tube of Respiration.—It sometimes happens that mines contain bad air in certain parts where it is necessary to work. This may occur at partitions, doors for ventilation, pumps, &c., and even in digging shafts and galleries. In all these instances, it is a better plan to conduct fresh air to the place, than to send workmen with respiration tubes, provided a blast machine is at command, which is strong enough to force the fresh air to the point where it is required. Any canvas bag is strong enough to conduct air to a workroom, and, if made sufficiently wide, a large quantity may be conducted by it. Muslin of a yard wide will form a pipe of 12 inches in width: when this is painted with oil paint it will last a long time, and a gallery or drift may be provided with air for a long distance. Some hoops are required, about a yard apart, to support the canvas, and form a round pipe. Through such a pipe, suspended overhead, a large quantity of air may be forced 200 or 300 yards, and sufficient to provide a set of workmen with air. When a temporary use is to be made of a respiratory tube, and that only for one man, common hose, 3 inches wide, made of leather or India-rubber, is employed. One end of it is either connected with the blast machine, and air forced into it, or it is exposed to the free atmosphere, and the men must suck the air into the pipe. The workman who uses the pipe is provided with a mouth-piece, which is firmly buckled to his mouth. His nostrils are closed by a spring made of steel. The contrivance assumes then the form represented in fig. 60. A short metal tube is screwed to the hose, and provided with two valves, one for inhaling the fresh, and the other for respiring the consumed air. These means, however convenient they may be in many instances, are expensive, and if fresh air can be driven to the vitiated place by the engine, it will be found more advantageous.

FIG. 60.



CHAPTER VII.

Drainage.—The draining of a mine is one of the most important subjects in practical mining operations. The waters which come down the walls in drops gather into little streams, and these, united, form in extensive mines a considerable body. The quantity of water which may be furnished by a mine, is not easily estimated beforehand. We can form some opinion as to the probable amount by reference to the kind of rock which we penetrate, and the capacity of the country for springs and wells; still this is no certain criterion, for the ground and rocks may be dry at the surface, and yet contain much water beneath. The rock may be covered by a layer of water-proof clay, which causes the surface to be wet and swampy; still, below it may be free from water, and a mine in such places perfectly dry. The elevation of a mine has an important influence upon the quantity of water which it may contain; most rock is accessible to water, which filtrates through its crevices, and gathers below. It will accumulate where the filtration is checked, and the rocks become saturated. Some rocks are remarkably dry, others contain much water. Volcanic rocks and limestone do not furnish much water to a mine; granite, also, is dry. The copper mines at Lake Superior, which are chiefly in trap rock, are remarkably dry. Stratified rock, of either transition or secondary formation, is dry at the surface when the strata is inclined, but there is abundance of water in its lower portions. A deep mine in the gold region of the Southern States is always found to be very wet. Are the strata of rock horizontal, or nearly so, the quantity of water is greater in the higher parts of the hills, than below. The coal region of the West furnishes sufficient evidence for this assertion. In all instances, the quantity of water in a mine increases with its surface, that is, with the extent of its workings, apart from any other circumstance to influence it. When crevices are opened in the progress of work, which communicate with reservoirs of water in the interior of the rock, or pools at the surface, springs are formed which frequently add considerably to the waters of the mine. When a mine penetrates through a water-proof bed of clay, gypsum, or a layer of limestone, the water is in most cases more abundant below than above such stratum. In most of the mines in operation, where a circulation of air is freely admitted, the quantity of water is generally greater in summer, spring and fall, than in winter. When the interior of a mine is warmer than the atmosphere, it will furnish moisture to the latter in its circulation through the mine; and when it is colder, it will condense watery vapors of the air which enter and increase the water. In all cases, attention must be given to the manner in which the water penetrates, that its direct effect on the workmen may be avoided. It not only annoys them, but delays the work, and causes the mineral unnecessarily to be more expensive, by interfering with the comfort of those engaged in its extraction.

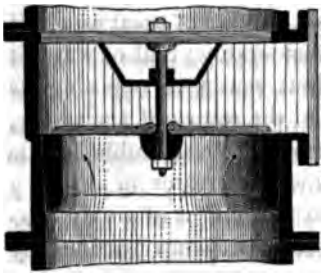
By Levels.—We have already alluded to the drainage by levels and ditches, and shall add only a few further remarks. In forming a water-drain in the pavement of a drift or a gallery, it is necessary to pay some attention to its form. The walls of the drain also should be smooth; not that rough walls cause much friction, and diminish the velocity of the water, but because all the water issuing from the workrooms carries along some impurities, particles of rock, minerals, clay, &c. This heavy matter will settle in rough, contracted or crooked channels, more than in smooth and straight ones; this sediment causes pools of water, which soon overflow the pavement, rendering the mine wet, disagreeable, and injurious to the health of the workmen. These defects may be avoided in some measure by giving more fall to the drain, but it will not remove the evils resulting from an imperfect form of the channel. When it is possible, the water channel should be located on one side of the gallery or drift, rather than in the middle of the floor. When the drain is covered by timber or planks, or a roadway, it is not easily accessible, and sediment may accumulate and overflow a portion of the mine before it is observed and can be removed. If the channel is on one side, it may always be uncovered, and any obstruction is soon detected and removed. In all cases, no matter where the drain is located, it should be easy of access at any time. If parts of a drain are necessarily covered, where there is loose rock or gravel, it is advisable to make such parts spacious and of mason-work. Wooden culverts are liable to decay, particularly in a mine; and if the location of the culvert is inaccessible, it cannot easily be replaced without much disturbance. This is the more serious if the road-way extends over such culverts. The size and fall of a drain is calculated according to the laws regulating the motion of water in canals; but as there are many modifications of those laws, on account of obstructions, we are not justified in referring to them. The location, size and fall of the drains is chiefly ascertained by observation. One foot fall in one hundred feet of length is considered sufficient in all instances; but as this, in long levels, causes a considerable loss in the depth of a mine, less fall is taken in many cases, and the size of the channels increased. One foot fall in one thousand feet causes a considerable current; but the water must be clear, or the drain is liable to obstruction. A deep pool provided at the head of the drain will retain most of the mud issuing from the workrooms and roads, and pass the water free from sediment. Such pools may be cleared of their contents when filled, and serve a good purpose in draining a mine to its lowest depth.

By Pumps.—Much ingenuity has been expended in the construction of pumps, in order to drain mines with the least possible expense. We shall not allude to the numerous forms of pumping-machines which have been contrived in past times, nor to many of the imperfect means for pumping at present in use. We shall, however, describe that kind of machinery which is suitable to perform the most labor with the least expense. We have spoken of the hoisting of water by means of the rope and barrel in former pages, and shall confine our present remarks to pumps only. Notwithstanding the progress in mechanics and the construction of machinery, we find men who waste time and means on the invention of machinery for lifting water, which never will successfully compete with well-constructed pumps. The principles governing the construction of pumps are not so generally observed as they should be. We state, for this reason, those laws which govern them.

Principles of the Pump.—There are three principal kinds of pumps,—the sucking, the lifting, and the forcing-pump; all these are used in mines, and often the whole of them in one set. The sucking-pump consists essentially of the cylinder, the sucking-pipe, the piston with its valve, and the sleeping-valve at the lower extremity of the sucking-pipe. When the lower end of the sucking-pipe is immersed in a reservoir containing water, and the piston in the cylinder raised, the air contained in the space between the piston and the sleeping-valve will expand, in proportion to the space evacuated by the piston. The density of the air without the pipe is greater than the density of that within, and pressing upon the water forces it into the pipe through the sucking-valve, so high as to produce an equilibrium between the external and internal air. As the air within is expanded in proportion to the space moved by the piston, an equal amount of water will be pressed into the pump to fill the space evacuated by the piston. The density of the air within and that without having become equal, the sleeping-valve shuts by its own gravity, and prevents the flowing out of the water from the sucking-pipe. The piston being now depressed, it will compress the air within; this causes the valve to open, and the air escapes through it. It is easily conceived that this play of the piston, when repeated, will raise the water to a certain height. It would raise it to an indefinite height if the air, or the gas formed by water in a vacuum, was not elastic. When the column of water thus raised is equal to the pressure of the atmosphere upon the vacuum, which height is indicated by the barometer, the piston may be raised, but it will produce only an elastic fluid. Either the water will evaporate and condense with the motion of the piston, or if there is any air in the pump it will expand and condense, following the motion of the piston. When nothing interferes with the motion of the water in the sucking-pipe, and when the piston closes perfectly air-tight in the cylinder of the pump, the water may be raised to the average height of 33 feet—the greatest height 34 feet. In practice this height never can be obtained for the following reasons. There is always a loss of height, because there is friction between the water and the pipe, which diminishes its motion. The sleeping-valve always loses a little water as it shuts. The valve of the piston loses also from the same cause; and if the piston does not fit closely to the cylinder, there is a loss of height in the water. As smooth surfaces diminish friction, particularly between fluids and solid matter, it is of great importance to make the interior of pipes as smooth as possible. The loss of power in the sleeping-valve is partly caused by the weight of the valve resisting the upward motion of the water, and partly by the impact of the valve when open, which prevents its quick return; and as the water suffers less from this cause, it will flow back before the valve is shut again. In both cases, it is, therefore, advantageous to make the valve as light as possible, in order to oppose little or no obstacle to the motion of the water. The loss in power, or in the height of water in the pump, is here in proportion to the weight of the valve. If a sleeping-valve covering one square inch weighed 15 pounds, it would not admit of the passage of any water, for that weight is equal to the pressure of the atmosphere. The weight of the valve causes therefore a loss in the proportion of its weight to that of the atmosphere. This loss is increased when we consider the impact of the valve. In the sleeping-valve of a sucking-pump there is therefore a considerable loss of power, which may be diminished or increased by altering the weight of the valve. The valve in the piston is not liable to the same objections as the sleeping-valve. If the piston valve is of great weight it will resist the motion of elastic fluids considerably; that of water it cannot affect but by the friction, which it causes in opposing its weight to the motion of the water. On the return of the piston, after having arrived at its culmination, a considerable loss is caused by the impact of the valve, which is greater in a heavy than in a light one. We see here, that the weight of a valve exerts considerable influence on the effect of a pump, particularly on that of a sucking-pump.

The form of valves is of not less importance than their weight. A poppet-valve, in the form of a flat dish, is the most imperfect, because it is heavy, and does not afford a favorable form for the passage of water. The conical poppet-valve is better than the flat dish. It causes less disturbance in the current than the first valve, but it loses water because it is heavy and shuts slowly. Balls and cones are valves working well in small pumps, but are inapplicable in large ones. In pumps for mines hardly any other form of valve can be applied to advantage than that of the trap-valve. We allude to these particularly in the following remarks: valves should be as light as possible, for their weight must be lifted by the moving power before any water can pass. If the weight of a valve is great, the power required for raising it must also be considerable. The weight of the valve should be so regulated that its pressure upon its bearing may be small, and that it may be raised with the least power. When the valve is raised to its maximum, it should be as light as at the bottom, that its tendency to shut may not be retarded by impact. It must be quicker in its returning motion than the motion of the water. We find here that the horizontal position of a valve is contrary to principle, and that a perfectly vertical one is the best. The vertical valve has its disadvantages in connection with vertical pumps; because it always requires curves to be made in the pipes leading the water to and from it. What is here gained in the form of the valve is lost in the curve of the pipes. It is therefore of little advantage to employ vertical valves; the same may be said of inclined valves; and the question rests then with the horizontal trap-valve only. There is little doubt that this form is the most advantageous; but there are objections to the common metal valve, and also to the leather valve. The common metal valve, as represented in fig. 61, is a good one, but in heavy pumps it causes strong vibrations, and requires constant repair. This valve could be fastened to a spring, either of steel or India-rubber, so that it would be repulsed in every position, and nowhere at rest. When a valve is shut with pressure upon it, it must be so far lifted by a spring as to balance its own weight, and also some of the incumbent pressure of the water; but the spring must not open the valve. When it reaches its highest elevation a spring should force it back in advance of the returning water.

Fig. 61.



If these conditions could be complied with in practice, there is no doubt but any kind of valve affording a large passage would answer. Such suitable arrangements with valves may be possible; but we do not know of any which perform well and which we can recommend. Recently a most perfect form of valve for water-pumps of limited pressure has made its appearance. In fig. 62 we have represented one form of this valve, and in the course of this chapter we shall allude to some others. The valve is here formed simply by a sheet of vulcanized India-rubber, $\frac{1}{4}$ of an inch

Fig. 62.

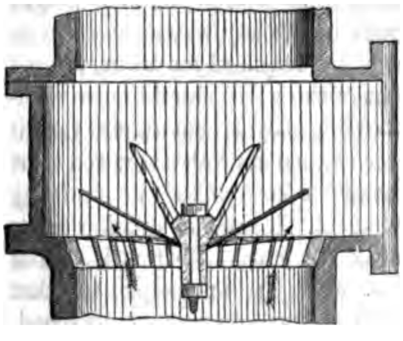
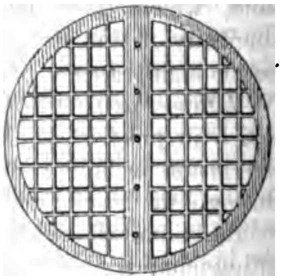


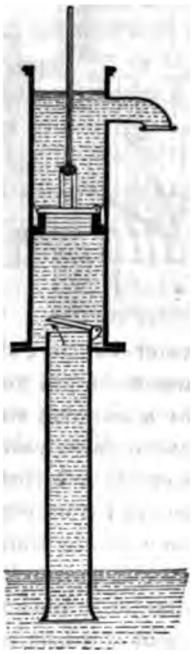
Fig. 63.



thick, in small valves, and increasing to ½ an inch in thickness in large valves. The under side, upon which the rubber rests, is represented in fig. 63. It is a cast-iron frame, round or square as the case may be, having a cross-bar in the middle of its area upon which the top and the rubber is screwed. The whole area of this plate consists of oblong openings for water, ¼ of an inch in width for small pumps, and from that to ½ an inch in width for large pumps, and a pressure of 15 or 20 pounds to the square inch. The oblong holes in this plate may form a grate like that in a stove, or the bars may be divided into compartments by cross-bars, which in the mean time stiffen the plate and prevent its injury by slight causes. The sheet of India-rubber which is screwed down in the middle, is easily lifted by the slightest pressure from below, and the openings in the bottom plate having a somewhat inclined direction, lift the valve very gently, and force it all at once to the full width against its angular support. It offers little or no resistance to the passing water by its own weight; it merely diminishes the passage for water. With the returning stroke of the pump, the water presses back upon the valve, passing through holes in the angular support. This valve causes less loss of power than the best valves of other forms; and gravity, which causes considerable contraction of the current of water in other cases, has little influence upon it. The small openings in the bottom plate occasion some loss of power by friction, but these holes may be polished, and in that case the loss is small. The greatest advantage of this valve is its soft bearing and perfectly close fit, which in mines is of considerable importance; because the waters of a mine often contain impurities and sand, which cause metal valves to close imperfectly. The simplicity of this valve is another recommendation which cannot be too highly appreciated in mines.

Lifting-Pump.—When water is raised in the sucking-pipe, which in practice should not be higher than 20 or 25 feet, and the piston is hollow and provided with valves, it will pass through the piston and ascend to any height we please. This height is limited only by the strength of material. In fig. 64 a lifting-pump is represented, which shows the sleeping-valve considerably above the lower extremity of the sucking-pipe. This arrangement is necessary where the sucking-pipe dips into an inaccessible pool of water. In such cases all that kind of machinery which is liable to need repairs must be easily accessible. It is not necessary to place the sleeping-valve in the cylinder, or close to the piston, as shown in the drawing. It is sufficient if the valve is above the surface of the pool from which the pump draws its water. When the water in the lifting-pump is raised to the height necessary for its discharge, a mouth-piece is appended to the vertical pipe, which may be directed to any point which well secures the flowing off of the water. In this case, as well as in that of the sleeping-valve, the form of valve and its operation has a decided influence upon the effect of the pump. If the valve in the piston is heavy it will press upon the passing water, contract the passage for it, and cause friction. If the material of the pump, that is, piston-rod, levers, or other machinery connected with it, is elastic, or if any gas is in the water, or the water warm, the elasticity thus produced will cause an oscillation in the column of water above the piston, and this by its impact will occasion a considerable loss of power, particularly when the column of water is high. It is therefore necessary, in order to produce the best effect in a lifting-pump, that the valves should be light and the machinery of the most rigid material. The above-mentioned valve, with iron pumps and machinery, is for these reasons the most perfect.

FIG. 64.



Of Pistons.—It is an essential condition in pumps that pistons should fit closely to the sides of the cylinder. This object cannot be obtained in square pumps, for which reason they are imperfect machines. Wooden cylinders are liable to abrasion, and consequently soon cause leakage at the piston, for which reason wood is a very imperfect material for pumps, even for those of low elevation. Wood is not strong nor close-grained; it is liable to filtration through its pores, and is therefore not suitable for making good pumps for high elevations. Pistons should fit tight in the cylinder, and afford as much opening for the passage of water as possible. In fig. 65 we represent a piston, which, according to our present knowledge, is the most perfect for a lifting-pump of limited height. It is made of iron or brass, as the case may be, cast in one piece, and turned. The packing is produced by a series of steel rings, one laid on the top of the other, so as to fit closely between themselves; these rings are spring-hardened, and their diameter is somewhat larger than the diameter of the cylinder of the pump, so that the elasticity of the rings may cause a close fit in all parts. These rings are held at the face of the piston and in their places by a circular ring screwed firmly on the top of the piston, so as to give but very little play to them. The length of one of these rings is a little less than the circumference of the cylinder, and the open space thus caused in one of the rings is covered by the sound part of the next ring. The piston itself forms a grate, similar to that represented in fig. 66, with this difference, that here no solid bar traverses the area. It is entirely composed of small bars and oblong or rectangular spaces; the centre, containing the piston-rod and the circumference, shows the only solid parts. Above the piston, some inches distant, a round plate is screwed to the rod, which is permanently fixed in its place. This plate is also pierced with a number of round holes, or forms a grating of oblong apertures, similar to those in the piston. A sheet of vulcanized India-rubber, larger than the last described plate, plays up and down with each stroke of the pump, resting either upon the piston, in the upward motion, or against the plate in the downward motion of the piston. In this manner the apertures in the piston are either shut or opened, according to the motion of the piston. The water thus passing through the apertures, finds a circular space around the plate above, which is its passage. In this arrangement a considerable loss of power is caused by the descent of the India-rubber sheet. This loss is

FIG. 65.

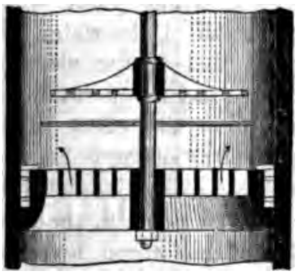
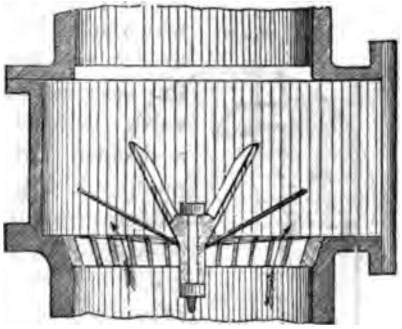


FIG. 66.



equal to a part of the distance traversed by the sheet, compared to the stroke of the pump. We may here employ the valve shown in fig. 66; but this diminishes the aperture in the piston by the solid bar in the diameter; still we are inclined to consider the form of fig. 67 superior to that of fig. 68.

FIG. 67.

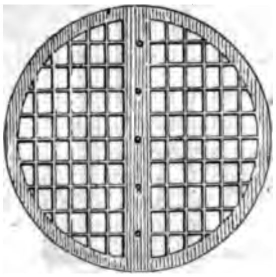
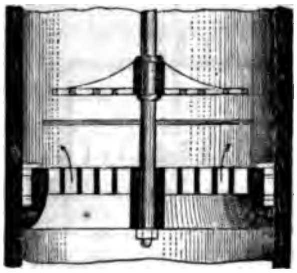


FIG. 68.



Force-Pump.—This kind of pump has no valve in the piston, by which it is chiefly distinguished from the lifting-pump. The piston is here solid, and the water is driven to some side-pipe in which the lifting-valve is fastened. In fig. 69 a common force-pump is shown. The solid piston is moving in a metal cylinder, which may be either of cast-iron, brass, copper, or other metal. The water is sucked from the pool by its upward motion, and drawn into the cylinder; when it returns or descends, the water is forced out of the cylinder, and the sucking-valve closes. The force-valve is now opened, which admits the water into a pipe, when it may be raised to the desired height.

We here very soon perceive what causes the chief loss of power in this pump. The water, in being drawn into the cylinder, has attained a certain direction in its motion, and when arrived at its maximum of speed and elevation, it is suddenly stopped and its motion changed. Water is almost inelastic, and any sudden alteration in the direction of its motion will create considerable resistance in its particles; it therefore reacts upon the piston, causing much loss of power. This loss increases more rapidly than the speed of the piston, and, perhaps, is not far from the cube of that speed. These pumps are not well adapted for use in mines. They require much repair, are expensive in the first cost, and also in consequence of loss of power.

Force-pumps similar in principle to the above, but different in construction, are extensively employed in English mines, and in water-works for supplying cities with water. This circumstance is a recommendation, but it does not make these pumps better; and if we blindly imitate what has been done by others, we may be led into the same error.

FIG. 69.

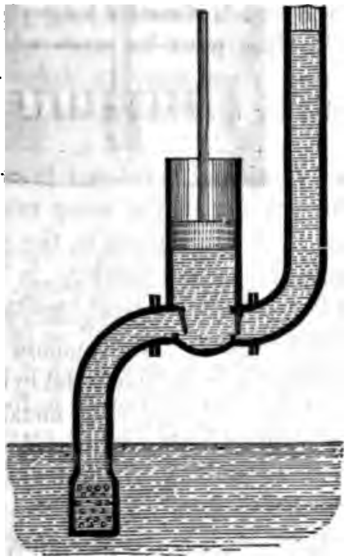
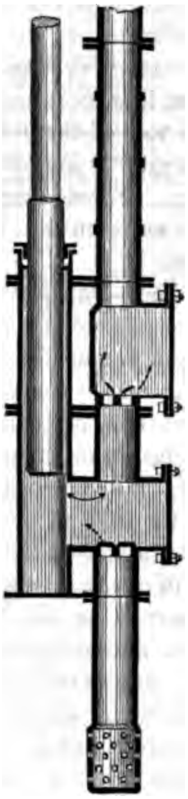


Fig 70



In fig. 70, is a pump of this kind. Instead of a piston a plunger is used, or second cylinder playing in the main cylinder, which latter is here a common strong cast-iron pipe. The only advantage this pump possesses over the above-mentioned force-pump, is the absence of the piston rod, which does away with the stuffing box for it, and also the friction caused by it. This, however, appears to be a small advantage, when we consider that the stuffing box for the pump, fig. 69, is a mere guide, and that a piston can be more accurately adjusted to the cylinder so as to afford a close packing than a plunger. The motion of the water is here the same, and a similar kind of action and reaction is produced, and the same loss of power must consequently ensue. These pumps are useful when an exceedingly slow motion of the piston is sufficient to raise the required amount of water. If a pump of this kind is chosen of sufficient dimensions to do the work with a slow motion, it will answer admirably well; but lifting-pumps of large dimensions work as well or even better. In leading pipes a long distance, or forcing water to a considerable height by one set of pumps, it is most useful to employ force-pumps, because when the piston rod of the lifting-pump descends through long pipes, its size is greatly increased, and the pipes must be made wide and strong. Force-pumps are therefore necessary in deep mines, where no room can be provided for a successive set of lifting-pumps.

Pipes.—This is a subject of considerable interest in relation to the drainage of mines by pumps; for all the water raised by the pump must be conducted in suitable pipes to the desired height; and as the expense caused in their purchase is an important item, it would be well to ascertain the most profitable dimensions, in order to avoid unnecessary cost as well as imperfect work. When a pipe is filled with water, or any fluid, it presses upon the sides of the pipe with a force proportionate to the head. Pipes must be equally wide throughout their length; no contractions of any kind should be permitted; even bulgings are disadvantageous to the motion of water when imperfectly made. Curves, and particularly sharp angles, are highly objectionable. If such angles or knees cannot be avoided, it is necessary to make the radius for the curvature as long as possible. When such a curvature is not a part of a small circle, and not an acute angle, its influence on the motion of water in the pipe may be neglected; but in all cases where a pipe turns short, or doubles an angle, the loss in power must be taken into the calculation.

The friction of water in pipes is considerable, particularly under great velocities. If we call V the velocity with which water flows in straight pipes, L the length of the pipes, H the height of water or head, and R the radius of the pipe, the velocity in the pipe will be

$$V = 53{\cdot}58 \times \sqrt{\frac{\frac{1}{2}R \times H}{L}}$$

It follows from this that the loss in power increases with the square of the velocity, and that the least velocity is the most advantageous in practice. Frequently we find the velocities in water conduit pipes great, and of course a considerable loss of power is experienced. As a rule, we may state that water should not move with a greater velocity than 4 feet per second in smooth and straight pipes. In curved pipes the velocity should be less, and in curved and contracted pipes still less. In the latter case the velocity should not exceed 2 feet per second, and this should be reduced one half if the pipe is longer than 100 diameters. We thus perceive that curves and contractions in pipes, to which roughness may be added, are imperfections which should be avoided by all means. They make it necessary to increase the width of the pipes, and thus the cost is increased.

The thickness required for pipes is determined by the pressure which may act upon their walls. The higher the water is in a vertical pipe, the greater is the pressure it will exert, and hence the strength of the pipe must be proportionate. As the tendency to rupture also increases with the diameter of the pipe, it follows that the larger the diameter the more metal will be required to withstand the pressure. If we call the diameters of two pipes D and d, the perpendicular height of water in the pipes H and h, and the thickness of the pipes T and t, we obtain the following equation, $T : t :: H \times D : h \times d$. When the value of one of these sizes for a certain material is known, we obtain the other very readily; that is, if we know that a certain pipe is strong enough to resist a certain pressure, we find the thickness of another pipe by substituting the values in the equation.

Experiments on various materials have shown that if we express $E = T$ in twelfths of an inch, H in feet, and D in inches, the strength of material must be as the following numbers. For lead $E = \frac{H \times D}{80}$; for cast-iron $E = \frac{H \times D}{200}$, and for wooden pipes with iron rings $E = \frac{H \times D}{4}$. The thickness of a pipe is therefore as the height, and it should increase with the latter. When a set of pipes of a certain height are properly constructed, the upper part may be either thinner, or made of a weaker material in case it is cheaper. Cast-iron pipes are the most common in mines, and in fact are the only practicable pipes; but as this material is liable to great variation in quality, and also the thickness of cast-iron cannot be depended upon for uniformity, we should increase the strength found by the above formula at least 25 or 30 per cent. We find, then, for a cast-iron pipe which is to bear a pressure of water 50 feet high and 6 inches in diameter, $E = \frac{50 \times 6}{200} = 1{\cdot}5$, or $\frac{1}{8}$ of an inch in thickness. Such a pipe cannot be cast, and we may assume that a cast-iron pipe of six inches bore must contain half an inch of iron. This would afford strength for 200 feet head, but as the formula indicates the extreme thickness, it is advisable not to extend pipes of half an inch metal and 6 inch bore lower down than 150 feet. Each additional 40 feet in depth requires one eighth of an inch additional thickness of metal.

The quantity of water furnished by a stroke of a pump is exactly equal to the space which is formed by the piston in the cylinder; that is, it is equivalent to the height of stroke multiplied by the area of the piston. If R is the radius of the piston, or bore of the cylinder, and S the stroke of the pump, the quantity of water furnished by each stroke $= R^2 \times 3{\cdot}1415 \times S$. The height to which the water is lifted has no influence upon this result. We assume in this formula that no water is lost by the valves, which is not the case, as we have seen above. As this loss depends upon the form of the valve, we cannot introduce a general coefficient which shall express it. The loss is often considerable, but as the water is not lifted which thus flows back, the diminution of power is not directly as the quantity, but a permanent part of it. Leakage between the piston and the cylinder is calculated on similar principles as the loss caused by the valves.

By actual experiment, it has been found that a man may lift 80 gallons of water in one minute 10 feet high, by a good pump. He will, therefore, lift 160 gallons 5 feet high, and 40 gallons 20 feet high in the same time. The labor performed by men, animals, and machinery, is always a product of time and power; and as a man or a machine can make advantageously but a certain number of motions in a certain time when applying their power, we are under the necessity of modifying the dimensions of a pump to the kind and form of motive-power which we employ. A man may make from 60 to 80 motions per minute without over-exertion; the contractions of the muscles admit of such a number; and if a man, or a number of men, are employed to move a piston directly, or by a lever, the dimensions used must be such that the power of the men can be profitably applied. The above standard, that is, 80 gallons lifted 10 feet in one minute, is a high result for a man's labor. It brings the unit of his power to 80 × 8 × 10 = 6400 pounds one foot high in one minute, a result which is, for the average of human labor, by one half too high. Here, however, as in all cases when we calculate the size of a pump, it is advantageous to assume a high standard of the unit power, because it will furnish a larger sized pump than a low standard. We take thus for one man, 6,400 pounds lifted one foot high in one minute; for the labor of an ox 15,000; for that of a mule 20,000; and for that of a horse 30,000; and for a steam-engine, or a water-wheel, 40,000 may be assumed. But as the elements by which the labor of such machines is estimated are exceedingly variable, we calculate the size of pumps according to the quantity of water which is to be lifted by them. A man may lift by his arms a certain load 80 times 2 feet high, and if he is to lift 80 gallons 10 feet high in a minute, he must lift 1 gallon 10 feet high with every stroke, or every motion of his body; and as his hands can move but 2 feet high, he must either apply a lever of 1 : 5, or lift the same quantity of water which is in the space of the 10 feet in height, only 2 feet high. We have seen above that water in pipes should not move with a greater velocity than 3 feet per second, and for practical purposes 2 feet are preferable to 3. When water is to be lifted 10 feet high 80 times in a minute, this will give a velocity of $\frac{80 \times 10}{60}$ = 13·3 feet, this divided by 2 furnishes a motion nearly 7 times too rapid for water in pipes. The dimension of the pipe must be such as to contain 1 gallon of water in 1·9 foot of length. If now the piston or the cylinder is equally wide with the pipe, the man must be placed so as to make 2 feet motion in producing 1·9 foot in the pump. The piston or cylinder of a pump is generally made larger in diameter than the pipes, because the valve contracts the passage in small pumps at least to one half, and the cylinder is for these reasons one half wider than the pipes, which causes it to have twice the area of the pipe. The velocity of the piston is therefore half that of the water in the pipes, and amounts to $\frac{1·9}{2}$ = ·95 of a foot for each motion of the man. This ·95 of a foot in length of the cylinder must contain one gallon of water, and as one gallon is one eighth of a cubic foot, the diameter of the piston must be, when a gallon is 215 inches, equal to 5 inches. In this calculation we have not estimated the loss of water caused by the valves. If we assume that this is $\frac{1}{4}$ of the whole amount of water raised by each stroke, the diameter of the cylinder must be 6 inches in order to furnish the 80 gallons per minute. To this pump a lever must be applied at the longest end of which the man works. As his motion is 2 feet, the leverage must be $\frac{\cdot 95}{2}$, or nearly 2 to 1.

This calculation is applied to a height of 10 feet, and if the motion is only two feet the area of the piston must be 5 times as large, or the stroke five times increased. If the height to which the water must be raised is 20 feet, the area of the piston can be half of that for ten feet, or the stroke of the pump must be diminished as the height increases. Ten times the height of water requires a piston ten times less, and ten times smaller pipes for the same amount of water. As the areas are as the squares of the diameters, the diameter of a pump is inversely as the square root of the heights, or as the square roots of the quantities of water. Generally, the diameters of pumps are $D : d :: \sqrt{H \times Q} : \sqrt{h \times q}$, in which formula D and d are diameters, H and h heights, Q and q quantities.

Loss of Power in Pumps.—The loss of power in a pump is caused by the friction of the piston on the sides of the cylinder; friction in the machinery which sets the piston in motion; and friction of water in the pipes and valves, and impact. The friction of a good metallic piston is not more than $\frac{1}{10}$ or $\frac{1}{12}$ of that of the power applied. Leather, hemp, or India-rubber cause $\frac{1}{3}$ loss of the power applied. The loss by friction between cast-iron and wrought-iron is $\frac{1}{7}$ of the moving power; it is less between brass and iron. Iron is very much corroded by the water of a mine, and if the first cost is not considered, it is advisable to line the pump cylinders or plungers with brass. The height of a piston should be at least $\frac{1}{6}$ of the diameter for metal packing; and for steel rings at least $\frac{1}{8}$ of that length should be the length of the packing. The friction caused by those parts of the machinery which set the piston in motion is equal to that of the piston itself, when well made. All other losses added to the above, increase the loss of power—in a good pump to one-third of the power applied; in ordinary pumps to one-half; and in ill-constructed pumps to still more than one-half.

Length of Stroke.—There must be a certain limit to the length of stroke; it is asserted, that in the largest pumps the stroke should not be more than 8 to 10 feet, and in hand-pumps proportionately less. We have seen on what basis the stroke of a pump is calculated for any power. That rule, however, would make the stroke in heavy pumps too short. A consideration which has most influence upon the length of stroke is the loss of water through the valves, which amounts to a considerable per centage in pumps with large valves and short stroke; and as this loss is uniform, and is the same for the long or the short stroke, it follows that a long stroke offers advantages in this respect. Another consideration is the size of the piston-rods; here the advantage is in favor of the long stroke, because the force required to move a small piston is not so great as that to move a large one, and the section of the rod may be smaller for these reasons. The only objection to the long stroke is the loss of power by increased friction in consequence of the diminished diameter. This loss however is not serious, considering the advantages of the long stroke. In this respect the force-pump with a plunger has advantages over the lifting-pump, because it has no valve and its size may be equal to that of the pipes, while that of the lifting-pump must be twice as large as the latter, and in very large pumps at least one and a half times that of the size of the pipes. We see no serious objections to any length of stroke, which is not limited by practical considerations. It may be urged that long cylinders cannot be bored correctly; this is no serious obstacle, for a plunger may be turned 40 feet long and be perfectly straight and round; and if the advantages of a long stroke are so favorable as to outweigh those of the lifting-pump over the force-pump, there is no objection to the latter.

Piston-Rods.—In large and also in deep pumps, the piston-rod is an object of particular attention, and various means have been suggested to overcome the objections to long rods. This circumstance alone, is sufficient to balance all the advantages which may arise from an inclined shaft. The pumps may be set vertically in all cases, but the pump-rods are subject to the direction of the shafts and drifts. In inclined drifts or shafts, a pump-rod is generally composed of a number of short rods, which are supported and connected by levers which rest on axes. In fig. 71, is represented a system of such rods. These are made of wood, mounted at the ends with iron. The whole system of these rods plays thus with the oscillating motion of the crank, and as they must be necessarily heavy, a great deal of power is lost by friction. Iron rods cannot be applied in these cases, because the distance from one support to the other must be made as long as possible. This is often with wooden rods 50 feet, and from that to 100, for one length between two supports. An oscillating motion of any power may thus be carried to a considerable distance; it has been extended in old mines to many thousands of feet. In vertical shafts, similar pump-rods are used; of course these are not supported at certain lengths; the wood is screwed together, and if the depth of the mine is great, the rods are supported by chains slung over pulleys. In figs. 72, 73, and 74, we show the arrangement as it is commonly made. The pump-rods are of wood, carefully spliced, and secured by layers of timber and iron hoops. The sticks of which the whole length is composed, are carefully straightened, hewn, and planed. We represent in the engraving three parts of the whole of a pump; an upper part, fig. 72, a middle part, fig. 73, and a lower part, fig. 74. The mine may be of any depth; the form of the upper and the lower parts is always the same; the middle part is made longer or shorter, or the number of pulleys increased, as circumstances may demand. We see here, the lower part of the whole set of pumps consists of a sucking and lifting-pump, all the other parts, however many there may be, are force-pumps with plungers. The weight of the whole length of the piston-rods, plungers, and all the moving appendages, is here equal to the column of water, or to the united sectional surfaces of the plungers, inclusive of the friction of the water in the pumps, and the friction in the machinery of the piston-rod. Hence, the weight of the piston-rod will in its descent set all the pumps in operation, and the engine which drives the pumps has merely to lift the

Fig. 71.

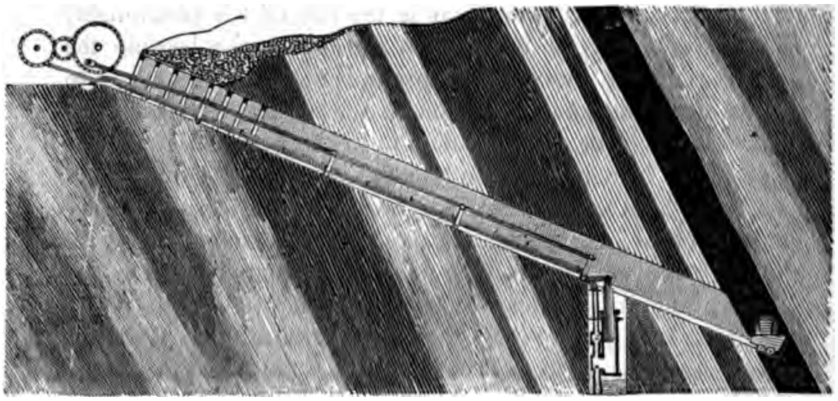


Fig. 72

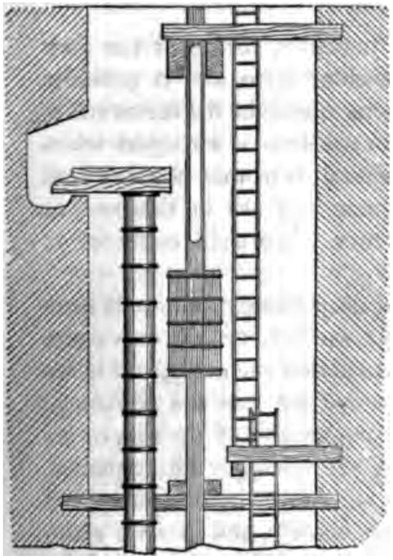


Fig. 73.

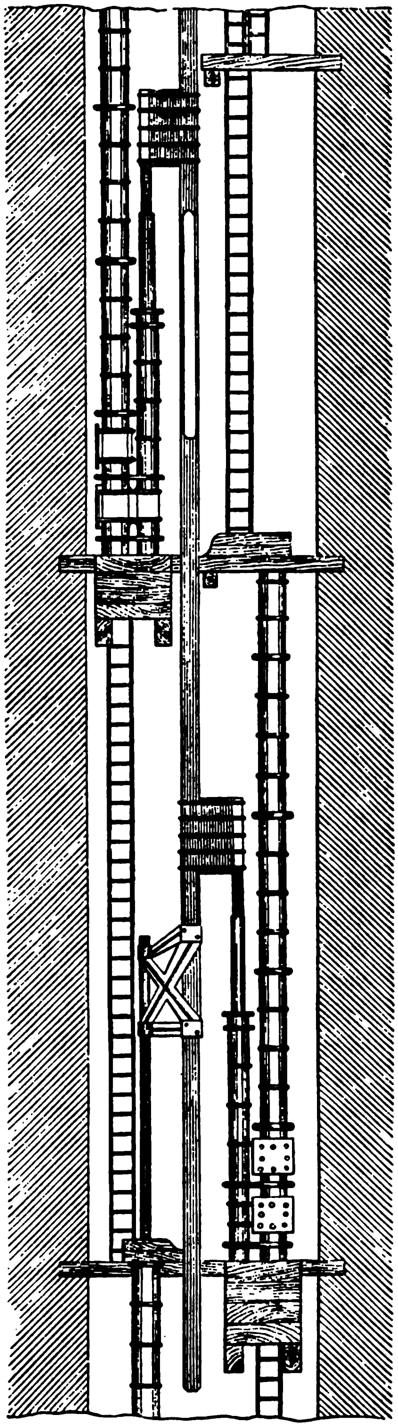
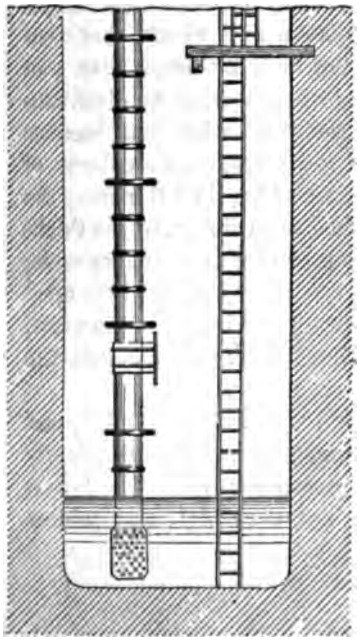


Fig. 74.



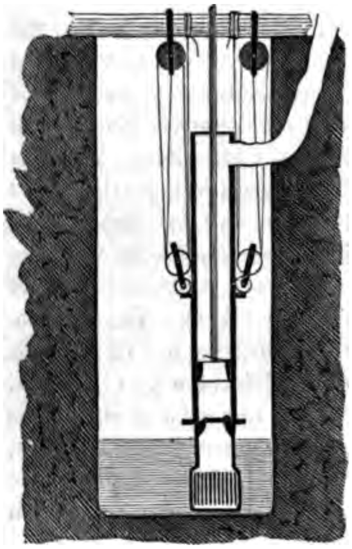
piston-rods. This arrangement is judicious, for by it the rods are prevented from receiving the pushing force, and it provides against vibrations. The rod has here to sustain the direct strain only; and as wood as well as wrought-iron is strongest when the force is directly applied, the material is in this position used to the best advantage. Wooden pump-rods are in this case, as in most others, preferable to metal rods. We shall endeavor to explain the cause of this hereafter.

In the construction of pumps for deep mines, pump-rods form a most important particular. They frequently are the only cause why a succession of pumps is set one above the other, and if we endeavor to limit the number of pumps, we lose the advantage arising from working the pump by the gravity of the rod, or we are exposed to injurious vibrations. If we apply lifting-pumps, we may raise a column of water to any height by one pump, but this requires generally ponderous piston-rods, and is soon abandoned, and the sets of pumps multiplied. This division of the whole height of a pump into various sets, is in many respects advantageous; the rods and the pipes may be lighter, and all the machinery connected with them, so that a number of pumps of a certain height each is preferable to one pump extending the whole height. In all cases where the height of one pump exceeds the advantages which may be derived from the peculiarity of the material of which the pump is constructed, we limit that height to the nature of the material. We have seen above, that cast-iron pipes of 6 inches in diameter cannot be cast thinner than ½ an inch. If we need pipes only 6 inches wide, it would be disadvantageous to take a less height for the pump than 150 feet, because cast-iron of that thickness can bear the pressure of a column of water of that height. If the pipes are wider than 6 inches, the height of the pumps must be diminished accordingly, or the thickness of metal increased. If the pump or pipe is 12 inches wide, the height can be only 75 feet, or the thickness of the iron must be one inch. Are the pumps narrower than 6 inches in diameter, either the iron can be made thinner, or, which is preferable, the height of the pumps may be increased.

One set of pumps is not often made higher than 150 feet, and from that to 100 feet. Each set throws its water into a firmly placed cistern, from which the next pump sucks it. The lowest set or the lifting-pump is generally not very high, and seldom exceeds 40 or 50 feet. The water in mines contains always a large quantity of air, which is mostly thrown out at the first pump: if this air is permitted to pass into the next pump an equal volume of water is replaced by air, and of course the pump does not throw so much water as calculated. The sucking part of the pump is for these reasons never very high, and often it does not exceed 8 or 10 feet. The pumps are lodged and fastened upon a part of the rock. In a vertical pit, this is excavated so wide as to admit the passage of the platforms and of the workmen; but the remainder of the space of the section is appropriated to the pumps. Such a projection extends often 3 feet into the pit, which forms, when in solid rock, a strong chin or bracket. The cistern rests partly on this bracket; the largest part of it, however, is sunk into the rock, a chamber having been excavated, with a floor on a level with the upper edge of the bracket. The bracket is generally some few feet high, and the shaft below resumes its usual form. The division of a pump in deep pits has also other advantages, one of which is that of collecting the water from each height of a set of pumps. The water in coming down from above one of the cisterns is gathered into it by means of an inclined gutter cut in the rock, or fastened to it, as shown in previous pages. If the depth of the mine is divided into various work-levels, the water from each level is gathered in the next cistern below it.

Setting of a Pump.—Whenever a shaft is sunk to such a depth as to require a pump, that is, if the use of the whim and the barrel cannot keep the mine dry, the first or lowest set of pumps is let down upon the bottom of the pit. It consists of a cylinder with a valve piston, and forms a sucking and lifting-pump. This is of a size sufficient for the whole depth of the mine, and when once lowered it is never raised again. It is suspended on two pairs of blocks or pulleys, as represented in fig. 75. It is well fastened above, so as to secure it firmly in its place, and the piston-rod, which is in the interior of the straight pipes, is secured by a stuffing-box. The piston lifts the water high above the top of the pump. At the upper part of the highest pipe a leather hose is attached, in which the water is either conducted to the nearest cistern, in case there is already a set of pumps fastened in the shaft, or to the surface, and discharged. This flexible hose allows the pump to be gradually lowered, as the bottom of the pit is sunk deeper by the workmen. In some cases the lower part of the pump, that is, the pipe with the basket, is replaced by a piece of strong leather hose, which is flexible, and may be put into any pool in the bottom of the pit, the workmen having previously made a cavity for gathering the water. In the drawing we represent the basket which dips into the water as composed of parallel rods, instead of round holes bored into the pipe. These oblong cavities do not fill so soon with debris of rock, and may be made narrower, affording still a larger passage for water than round apertures. In some instances the lowest part of the pipe is provided with a trumpet-shaped mouth, and a basket is attached to the pipe. The latter arrangement offers more basket surface, and is not so liable to be filled by particles of rock as the pierced pipe.

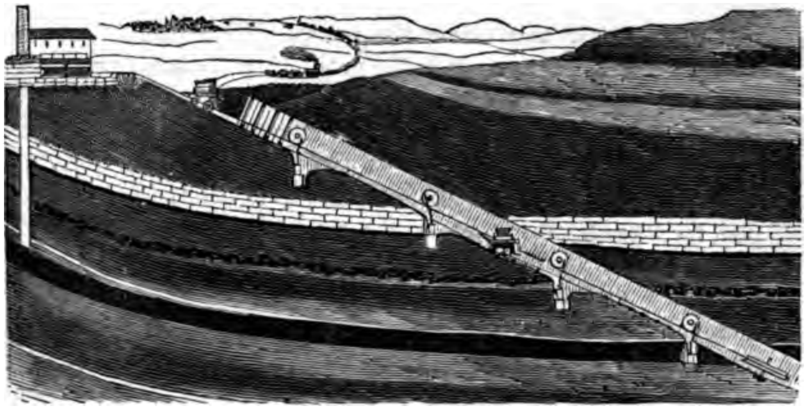
Fig. 75.



Proposal of a new method for setting Pumps.—Most of our mines are not very deep, seldom more than 300 or 400 feet. Those of the latter depth are very few; most of them also are little below the water levels of the country, and many years may elapse before our miners are compelled to extract mineral from deep ones. Many of the mines, however, contain large quantities of water, which prevents the working of them. The means required to erect an expensive pumping-machine are comparatively great, and in most cases it is not certain that the mines will repay the expenses incurred; we therefore propose the following arrangement, which may in some instances facilitate the working of a profitable mine, now dead for want of means to construct a sufficient number of pumps.

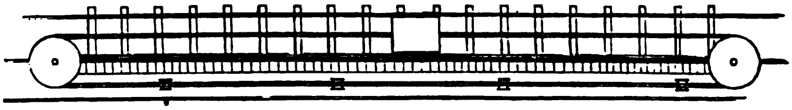
Any mine may be worked by means of inclined shafts, and if they interfere with the erection of common pumps, and also with the hoisting apparatus, the difficulty may be remedied if the machinery is adapted to the peculiar form of the shaft. The excavating of an inclined drift or shaft is on the whole not more expensive than that of a vertical shaft; its length is greater, but the work may be performed with more ease and on lower terms for the removal of the same amount of rock. We represent in figs. 76 and 77 this system, and shall point out its advantages presently. Fig. 76 shows an inclined shaft, whose slope may be more or less than 45°, but in all instances it should be sufficient to admit of the use of carriage platforms on which the cars from the galleries may be driven and hoisted as they come from the workrooms. The shaft has the width for one track of railroad, calculated to carry as much mineral as the mine may furnish; the platform being of sufficient size for taking as many cars as may be required for one trip. The hoisting is therefore done all on one track, and as a wire rope may be made sufficiently strong for any load, no matter how heavy, there is no objection to its hoisting all the mineral on one platform. The platform thus travels up and down on the same track, which causes apparently a loss of power, but not in reality, as we shall see presently. The wire rope which passes around a guiding pulley below, is wound upon a drum on the top of the slope, or it may be conducted over a grooved pulley and worked by adhesion. A drum connected with the engine at the top, upon which the rope winds, has great advantages in respect to the durability of the rope, but where economy in first cost is an object to the miner, the grooved pulley may answer the purpose. One-half of the shaft is allotted to the pumps and the stairs by which the miners descend and ascend. That part in which the pumps are distributed is more

FIG. 76.



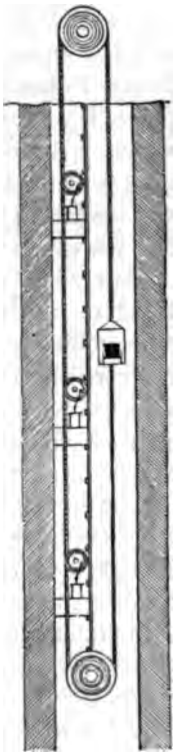
distinctly shown in fig. 77. We see there the wagon-track for the platform, and a number of pumps distributed along the second rope. At each pump is a pulley, around which the wire rope is slung, and this drives the pump. We represent in the drawing the pumps as sunk in the ground; there is no necessity for doing this; they may be laid on the floor of the drift or posted upright. As to rotary pumps, any kind which will furnish most water by the application of the smallest power is right. One condition, however, must be observed in determining on the plan for these pumps; that is, the rope travels backwards and forwards, and the pumps must work to both motions. Pumps which are driven by a crank offer no difficulty in that respect, although some kinds of rotary pumps work only in one direction. Any number of pumps may be employed with the greatest facility; and if expense is a consideration, the cheapest kind of pumps, those which throw water but 40 or 50 feet high, may be used. If, in the course of the work, it is found that the pumps in operation are too small for the labor assigned to them, an addition to their number may be made instead of throwing the old pumps out. The leading principle is here to employ a large number of small pumps, of limited lift, instead of only a few reaching to a great depth, and lifting with each set to the height of 150 or 200 feet.

FIG. 77.



This system of working a mine is not confined to the slope; it may be used to equal advantage in the vertical pit or horizontal drift, as is shown in the following figure. The inclined pit is, however, cheaper than the vertical one; and as the objections to it are removed by this kind of machinery, we consider it to be the most advantageous form for hoisting, pumping, and ventilation. If this inclined pit is of the same size as a vertical pit, and if its length is greater than the latter, it may be excavated cheaper, particularly in stratified rock. A cubic yard of a vertical pit will cost at least twice the price of a cubic yard in the horizontal drift; and if the work in the slope cannot be done quite as cheap as in the drift, it will cost but little more. In all instances there is not much more room required in the slope than in the shaft.

Fig. 78.



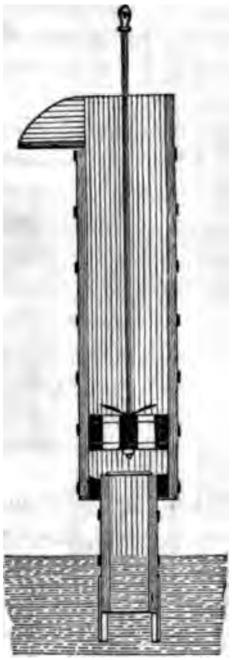
In fig. 78 we represent the same principle adapted to a vertical shaft. In fact it does not make any essential difference if the system is applied either to the one or the other form of entrance. The chief objection to the vertical shaft is its admitting only a small platform, which, even if it takes as much mineral as the large platform of the slope, or that of the drift, it requires more time to unload. Assuming that in most, if not in all cases, the dog-cart is the most profitable in our mines of limited extent, that cart must be admitted upon the platform at once, and also easily removed. When a large quantity of mineral, such as coal, is to be hoisted, a number of carts must find room at once on the platform, without being much crowded. It is not objectionable to make the platform of an inclined plane in the form of steps, so that it may afford a large area. To this arrangement there is, however, some objection in the vertical pit, because it would require a high tower to bring all the platforms, if more than one, above ground and unload them with dispatch. It needs scarcely to be stated that the rope which drives the pumps requires no greater strength than is necessary for that purpose. Either rope, it may be that for hoisting or for pumping, has its peculiar size. Both ropes need not be of equal size.

In respect to ventilation, this system offers peculiar advantages. Where no air-shaft can be located conveniently a blower may be placed at the bottom of the pit, and driven by the guide pulley. The changing rotation of that pulley is no objection, for if a common fan-blower with radial vanes is employed, it does not make much difference which way it is driven. The blower is here at the best place in the whole mine. The air is here heaviest and of most force.

Various Forms of Pumps.—In conclusion, we furnish various forms of pumps now in use, and select such specimens as are most suitable to secure the desired effect with the least labor and expense. When water is to be lifted only 2 or 3 feet, the use of the common water-bucket is about as profitable as any instrument we could apply, particularly if no other motive power but that of man can be employed. If circumstances admit of the use of animal power, or water, or steam-engines, these of course are preferable to human labor, because they are cheaper. If a unit of power is represented in that of a horse-power in the steam-engine, which is by general agreement 33,000 pounds lifted one foot high per minute, and we calculate the cost of that unit in the various means by which machinery or pumps may be driven, we find the expenses for one hour as follows:—The cost of that unit of power in a water-wheel is very small, and amounts to the interest on the capital invested. If we neglect this item in all cases, which properly may be done, because it is variable and depends chiefly on localities, we find the cost of one horse-power in the water-wheel per hour a mere nominal sum. The same unit causes in a Cornish steam engine the use of 3·5 pounds of coal, to which the wages of engineer and fireman, and also the cost of repairs must be added, which may increase the expense about 1 cent per hour in large engines, and 2 cents in small engines. The price of coal is very variable in the United States, and so must be the cost of power in a steam-engine. A common engine, with crank and fly-wheel, well made, and of at least 100 horse-power, will consume 5 pounds of coal for the same power. A steam-engine of less power and high pressure, will consume 10 pounds; and a small engine, of from 15 to 20 pounds of coal per hour and per horse-power. The actual cost may be little more than 1 cent in the best engines, and about 10 cents in small engines and with high-priced fuel. A unit of power will cost in a horse from 20 to 50 cents; in the ox and mule about the same. Human labor will cost at least $1 for the amount done by the water-wheel for nothing, and by a good steam-engine for 1 cent. As the lifting of water is an operation which requires constant and in most cases great power, it is well worth while to give close attention to the engine which drives the pumps, and to the construction of the pumps also.

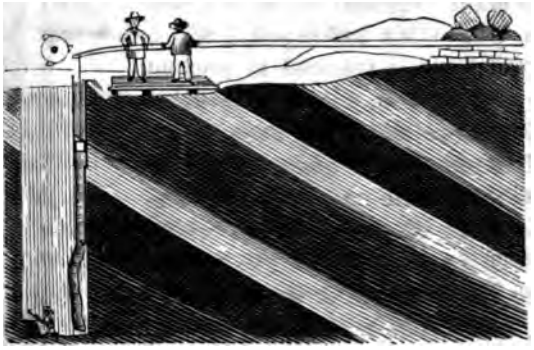
If water is to be lifted only ten or twelve feet high, wooden pumps may answer the purpose; but as in this instance a saving in the cost of labor is of importance, the common wooden pump will not answer. Where only a small quantity of water is to be lifted, the common hand-whim or horse-whim is used, as described in previous pages, together with the barrel or kibbel, the use of which is limited to small mines or small quantities of water. A wooden pump is represented in fig. 79. It is constructed of two-inch plank, and well provided with iron hoops for securing its joints. The lower part of the pump has a short sucking-pipe, and some projections to sustain the lower extremity above the bottom of the pit. This sucking-pipe, which may be 2 feet long, is required to prevent fragments of stone from entering the valve and pump, because these will drop in the downward stroke of the pump when the water is at rest in the sucking-pipe. The piston is a block of wood through which some auger-holes are bored. The piston-rod may be either of iron or wood; in the latter case it should be mounted with iron, in order to fasten it firmly to the piston. The valves are made of sole-leather, or, what is better, vulcanized India-rubber, provided on the upper side with a piece of sheet metal, riveted to the leather. The latter must be large enough to cover the whole area of the opening, to prevent injury to the leather. These pumps may be made 12 inches square inside, and even wider than that, but it is not profitable to make them less than 6 inches square. Water cannot well be lifted with these pumps to a greater height than 12 feet.

Fig. 79.



Spring-poles for Pumps.—The means by which to cause the oscillating motion of a pump piston are various. The crank appears to create the most imperfect motion, for any pump to which it is applied furnishes less water than when other means are used. Human labor is generally applied to a lever of unequal lengths, on the longer part of which the moving power acts. This appears to be the most profitable form of applying the power to common pumps. On board the flat-boats, on the western rivers, a kind of square pump is in use, which is very imperfect so far as the pump itself and valves are concerned, but a man may throw a large quantity of water with one of them. These pumps are provided with a spring-pole instead of a lever. We have found this to be an efficient means of conducting power to the pump, and consider it the cause of the large quantity of water raised. In adapting spring-poles to other pumps, the quantity of water raised is greatly augmented. The arrangement is in this case as represented in fig. 80. The rationale of this operation is as follows.

Fig. 80.



When the elastic spring-pole is depressed with the piston to the lowest point, the depressing force relaxes, and the pole returns to its former position, lifting the whole column of water by its elasticity. The change of motion is here very sudden, and tends to close the valves quickly, so that not much water can return through them. The rod, in moving the column of water with a great velocity, will mount to a higher point than actually belongs to it when at rest, and return from that elevation quickly. This returning motion may be assisted by the moving power. The sucking-valve also is here forced to shut quickly for the same reason as the piston-valve. Another advantage may be found in the mode of applying the muscular powers; the upward stroke being performed by the rod, the muscles of the men are free to relax and gather fresh energy for the next stroke. We allude to this as an important aid in the motion of pistons in pumps. This spring-pole produces quite the reverse of the crank motion, when the latter is converted into linear motion. A quick change is caused by the elastic spring-pole, and a slow change by the crank. If the same power and pump furnish more water when worked by means of the first, than by the latter, the principle involved in the motion of the first must be more correct than in the latter. This applies, of course, to pumps generally. In constructing pumps, and particularly the connection between the moving power and the piston, we should apply this aid in all cases. When the pump is driven by horses, oxen, a steam-engine, or a water-wheel, which power cannot be employed like that of intelligent men, we should apply that force to an elastic medium capable of producing a similar motion as the spring-pole. We indicate in the drawing the application of a uniform rotary motion, by means of cams to the piston-rod itself. This may be adapted to a communicating lever, or a prolongation of the spring-pole; but in no case will it work to advantage when applied to the spring-pole itself, at a place between the pump and the fixed point of the spring-pole. It is not necessary, and is also impracticable, to employ a spring-pole at large and permanent pumps, but by whatever means the motion is produced, it should be of this nature. The elastic medium has an improving and regulating effect upon the action of a pump. In attaching steam power to a pump it is therefore proper to dispense with the fly-wheel, and apply the steam directly to the piston-rod, or a rigid connection with it. We observe here that an elastic piston-rod will be productive of the reverse effect produced by the spring-pole.

In fig. 81 we represent a lifting-pump, composed of iron pipes, and a wooden piston-rod; the latter is shod with iron, where it is connected with the piston. In fig. 82 are two sections of the piston, the packing of which may be taken out and put in from below, so that both sucking-valve, lifting-valve, and packing are accessible from the one valve chamber, and the piston-rod need not be drawn when any thing happens to the piston, or when the packing or valve is to be replaced. The packing is here protected against coarse sand and stones by the upper part of the metallic piston, which is made so large in diameter as to close very near to the sides of the pump. A strong iron hoop is bent over the sucking-valve in the form of a protecting arc, in order to prevent injury to that valve by the piston, in case it should drop.

In fig. 83, we represent a forcing-pump with a descending plunger, which may be considered a specimen of a good pump of this kind. The weight of the plunger, which may be modified by inserted weights and piston-rod, is here calculated to force the water into the lifting-pipe. As the changes of such a heavy rod cannot be aided with a spring-pole, the valves must not open too far or they will be liable to lose much water. The packing of the stuffing-box may be hemp; vulcanized India-rubber is however better; leather is frequently used, but anti-friction metal, or brass, is preferable to either. The sucking-pipe is never very

Fig. 81

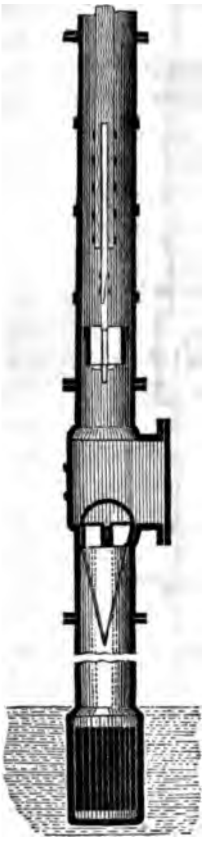


Fig. 82.

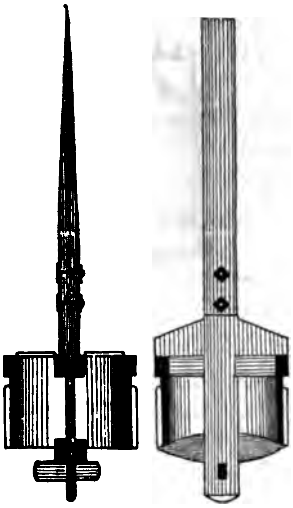
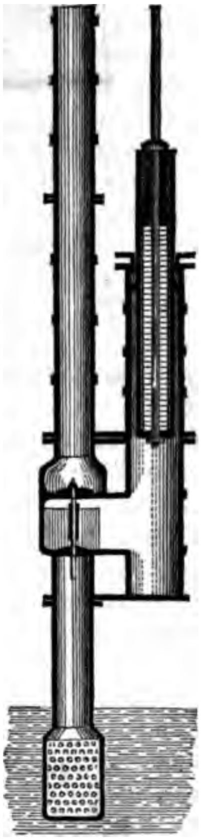


Fig. 83.



long in these cases, that it may not lose much water by the liberation of air from the water.

Fig. 84 is a drawing of a pump of the largest kind; the sucking-valve is represented as being open, and the forcing-valve shut; the piston is half-stroke, and ascending. This kind of pump works very advantageously owing chiefly to the peculiar arrangements in the valves. As this is an object of importance, we furnish the valve in various figures, which represent sections and views of it. Fig. 85 shows a vertical section of the valve when open;

Fig. 84.

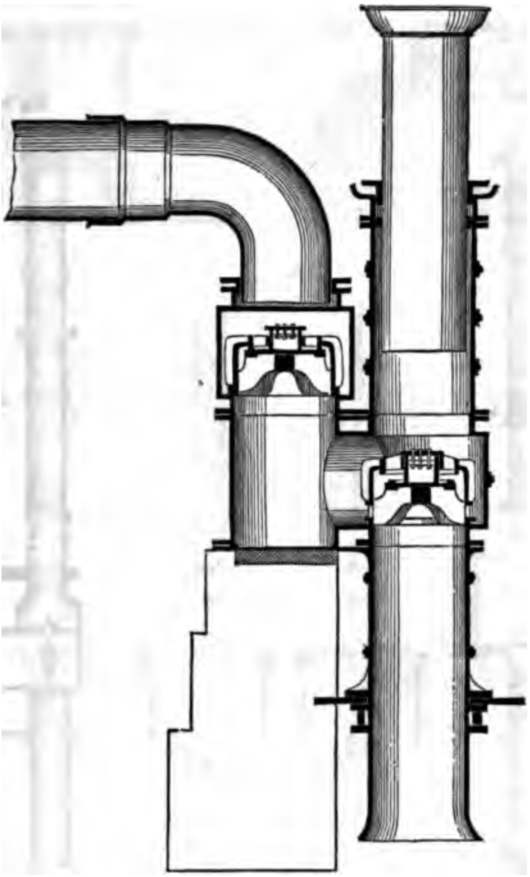


Fig. 85.

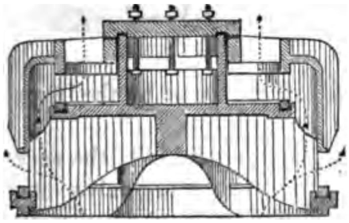
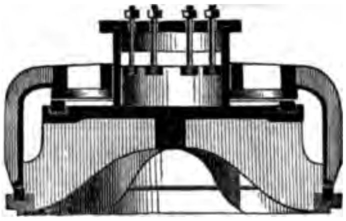


Fig. 86.



the movable part, as is seen, rises to a small height only, and consequently shuts very quickly, affording a large passage for water.

In fig. 86 the valve is represented as shut. Fig. 87 shows a view of the valve shut. Fig. 88 is a section of the immovable part of

FIG. 87.

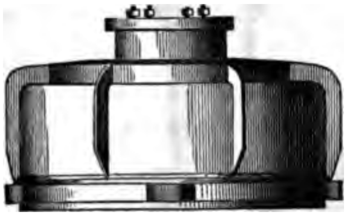


FIG. 88.

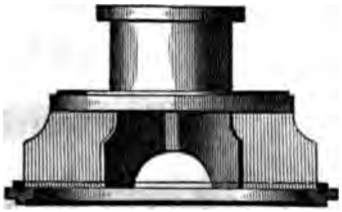


FIG. 90.

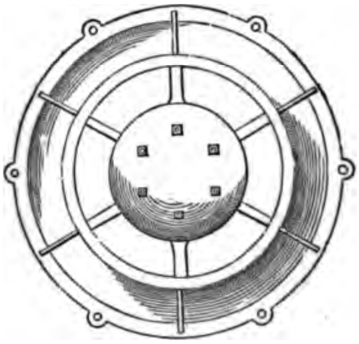
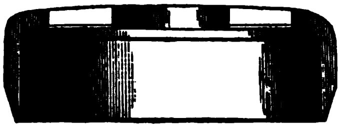


FIG 89.



the valve; and fig. 89 a section of the cap or valve itself. Fig. 90 is a view from above.

PART SECOND.

GENERAL METALLURGICAL OPERATIONS.

CHAPTER I.

Assaying.—This term was formerly confined to the analysis or separation of the precious metals from other metals; and to the determination of the quantity or value of gold and silver in bullion, coin, plate, or trinkets. We apply this term to the operation which decides the quantity of a certain kind of metal contained in an ore, or in an alloy, if it is performed by heat chiefly, in contradistinction from analysis, or the operation by moisture. Assaying is therefore a kind of analysis in the dry way; and as all, or nearly all, of the metallurgical operations are performed in this manner, the analysis of ores must be conducted by the same or similar means. In most cases we want a certain kind of metal separated from the ore, and if it should happen that two or more metals are connected, so as not to be separated in the first assay, we must adopt a subsequent process. Other particulars are of little interest to the practical metallurgist; he may in an approximate manner determine the compounds of the metallic ore, and arrange his fluxes accordingly, but the definite quantity of these foreign admixtures he cannot detect; these are to be investigated by actual trial on a large scale. The metallurgist may find the exact composition of an ore by the moist analysis; but that analysis does not assist him in forming a plan of operation in the smelting furnace. And when we consider that the moist analysis requires much time in its study, and more still in its practice, we cannot perceive any great advantages in its application by the metallurgist. Imperfectly performed, the moist analysis may do more harm than an imperfect, dry assay. For these reasons we shall not introduce the moist assay in this work; it is a useful auxiliary to the highly experienced metallurgist, but it consumes more time than the practical man can spare. The moist analysis belongs to the chemist, and the dry assay to the metallurgist.

The Blow-pipe.—This instrument which is represented in fig. 91 in one third of its natural size, is a pipe of thin sheet brass, or a glass tube drawn in the proper form and represented in fig. 92.

Figs. 91.

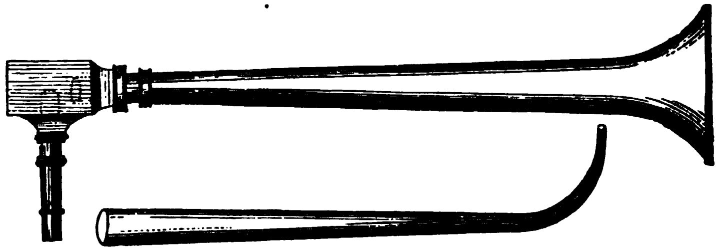
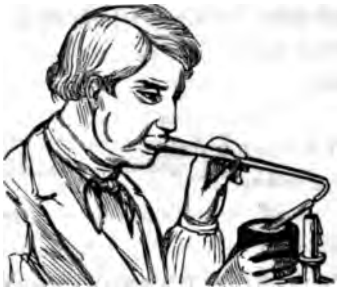


Fig. 92.

The latter form may also be given to a brass tube. The blow-pipe is used to obtain a high heat by forcing atmospheric air through a common flame of oil, tallow or wax, or alcohol. There are various forms of the blow-pipe of no interest to us, such as the table and the oxygen-hydrogen blow-pipe. The instrument represented above is quite sufficient for all our purposes; it forms, with a few fluxes, a complete laboratory to the metallurgist. By putting the mouth to the wide end of the blow-pipe, and urging a blast of air horizontally through the flame of a candle or a lamp, the flame will assume a horizontal or inclined direction, instead of the vertical one. The white light of the flame disappears entirely, and a blue cone of light with a yellow inclosure represents it. The more moisture the air contains which we force through the pipe, the more reddish yellow is the flame outside and dark inside. In order to condense the moisture the blow-pipe, fig. 91, has been contrived; the moisture which is blown in by the breath is condensed in the wide part at one end, and does not disturb the flame. This kind of blow-pipe is more useful for our purposes than that of the jeweller, fig. 92, because the presence of moisture is injurious to some tests. The opening which is inserted in the flame, and which produces the jet, should be round and about the size of a small pin.

Any flame will serve the purpose of some experimental tests, but not of all. A wax flame, or an oil flame, is the most generally useful; alcohol serves in a few cases for roasting. To furnish particular information as to the mode of forming the flame is not required; a few experiments will soon enable the operator to succeed in his attempts at producing a continual, uniform current of blast. In fig. 93 we represent the manner in which the blow-pipe is applied. The cheeks are slightly distended, the air drawn in by the nostrils, and in that way a uniform current is produced at that extremity of the blow-pipe which is held in the flame. The flame thus produced by the candle and blow-pipe may be made to turn in any direction; the current of blast directs the flame in its course. Within the cone of flame thus produced, there is an excess of oxygen, and the flame itself is hardly visible; the exterior of the cone having little oxygen is reddish often, but always free from white light when the flame is properly conducted and the candle in good trim. The extreme end of the blue interior flame is hottest, and is in some measure a reducing flame; here is an abundance of carbon which is inclined to combine with more oxygen. Metallic oxides, therefore, in being held in this part of the flame, are often reduced to metals. The tip of the flame, that is, that part where all the oxygen from the atmosphere is concentrating, has an excess of oxygen, the temperature is here very high, and metals held in this extreme part of the flame will oxidize. The flame thus generated by the force of the blast is directed upon the substance under examination, which is placed upon a piece of hard, close charcoal, made of beach or sugar-maple wood, the best face of which is selected. A small cavity is then scraped into it with the blunt point of a knife, and the hole carefully examined for fissures or cracks, into which a globule of metal may pass.

FIG. 93.



Re-agents.—Charcoal is a powerful re-agent, assisting in the detection of substances which cannot be found without its aid. It is therefore not an indifferent matter to see what kind of charcoal we employ. In most cases hard charcoal is preferable, because in most of our tests a high heat is required, which soon destroys soft charcoal, such as pine and willow. When very fusible metals are under treatment it may be advantageous to use soft charcoal, but these cases do not happen often. The property of non-conducting heat in charcoal is of considerable influence in this process; we cannot reduce any metallic oxide on a coke or anthracite support; they may serve for roasting or oxidation, but they cannot assist in reduction. In this respect the support co-operates with the flame. Good charcoal, made of young wood, will imbibe the slags which may be formed by the operation, and reject the metal; bad coal, or open coal, will absorb both metal and slag.

Carbonate of Soda is an invaluable material in vitrifying the foreign admixtures of a metallic ore; it absorbs silex, alumina, and other earths which are commonly interfering with the process of reduction. It removes these bodies from contact with the oxides which are to be reduced, and exposes the latter to the influence of carbon, which takes away their oxygen. When we want to know if a substance is soluble in soda, that is, to test it only, so far as to ascertain if it is an alkali, or an acid in respect to soda, we mix some soda with the substance finely powdered, and expose it, fastened to the point of a wire, to the influence of the flame. We may also dissolve sulphurets, such as iron or copper pyrites, in carbonate of soda, and by these means make the ore soluble in water, which will extract the soda and leave the sulphuret in the form of a fine powder at the bottom of the vessel. Many oxides may be recognized in the flame when in contact with soda.

Cyanide of Potassium.—This is a very valuable re-agent in the operations with the blow-pipe; it reduces, and in the mean time fluxes the test. This substance, when used somewhat to excess, will reduce the most sensitive metals, such as antimony and arsenic. It reduces oxides and sulphurets with equal facility. When this flux is pure, it fuses readily; but when impure, it is more refractory, and must be mixed with some carbonate of soda, or in some instances with borax. This mixture is the most useful and effectual in all operations with the blow-pipe; and if no other substances can be obtained, these ought to be at hand always.

Borax.—This substance shows a strong affinity for metallic oxides, and it will dissolve them either singly or in combination. It disposes sulphurets to decompose in order to combine with their metallic oxides. It is the most important substance for testing the nature of a mineral. When common borax of the shops is heated, it forms at first a white spongy mass; and if we continue to heat it, pressing it down into a clay or Hessian crucible, it melts at a brown-red heat into a clear transparent glass. This glass when pounded fine is the substance which we make use of in blow-pipe experiments. When we heat a platinum wire to redness, and dip it into powdered borax, it will, when heated again, form a round globule of borax glass at its lower extremity. This globule is brought in contact with the hot specimen to be tested, and the flame applied; it will now absorb some of the hot specimen, dissolve it, and show by its color what kind of mineral is under examination. This test must be made by means of the spirit-lamp, or alcoholic flame. The color of the glass formed, when cold or warm, when in the oxidizing part of the flame, or in the reducing flame, is in many cases a decisive test, if it forms metal in the latter, or merely changes its color.

Minerals are very seldom pure, that is, consist of one metallic basis; many are, however, so little adulterated with other matter that a test with fluxes and the oxidizing flame of the blow-pipe is of great service. We will mention here some few tests of this kind. Lime is infusible by itself, but gives a strong light; with borax it melts into a colorless glass. It is not soluble in carbonate of soda. Both, when heated together, are absorbed by the charcoal. Magnesia acts like lime. Alumina is infusible by itself; it melts with borax into a colorless glass, and if much alumina is present the glass is opaque: carbonate of soda does not dissolve this substance. Oxide of antimony sublimes by itself, and colors the flame a greenish-blue; with borax it forms a yellow glass when hot, and colorless when cold, in the oxidizing flame. In the reducing flame it forms a gray vitreous mass, and shrinks. With carbonate of soda, or a mixture of cyanide of potassium and soda, it forms a metal which easily evaporates in white smoke in the flame. The metal is very fusible and brittle. Oxide of bismuth is fusible, and forms on wire a dark-brown glass while hot, and a yellow glass when cold; it forms metal on charcoal, and with borax it melts into a colorless bead. With carbonate of soda, it forms metal on a coal support. Oxide of chrome does not change in the flame when alone; it forms with borax a bead which is red while hot, but changes into green when cold and under the oxidizing influences: when the mixture is exposed to the reducing flame it is always green. With carbonate of soda it melts to a dark orange glass when hot and oxidized, and becomes opaque when cold. In the reducing flame it is always opaque and orange, changing to green when cold. Oxide of cobalt is unchangeable by itself, but it forms a characteristic deep-blue glass with borax. It is reduced on charcoal when mixed with carbonate of soda, forming a gray magnetic powder. The oxide of copper fuses in the oxidizing flame; in the reducing flame it forms metal: with borax it forms a green glass in the oxidizing flame, and in the reducing flame brown-red; with soda it is reduced on charcoal, giving malleable metal. Peroxide of iron is unchangeable in the oxidizing flame; in the reducing fire it blackens and becomes magnetic oxide. It forms a bright-red glass when heated with borax, which changes to a pale dirty-red when cold, in the oxidizing flame. In the reducing flame it forms a bottle-green, often black-green glass. With soda, or alkaline flux, it forms metal on the charcoal support, which appears as a dark magnetic powder. Oxide of lead shows at first a clear blue flame, after which it fuses to an orange-yellow glass; on a charcoal support it is reduced to metal. With borax it forms a yellow glass when hot, which is nearly colorless when cold. When this oxide is mixed with alkaline flux, it forms metal instantly on charcoal; in the alcoholic flame, on wire, it forms a transparent yellow glass with carbonate of soda. Oxide of manganese is infusible alone, and changes its colors to brown; with borax it melts to a black glass when much manganese is used; when little oxide and much borax are melted together in the presence of carbon, the result is an amethyst-colored glass; and if brought within the reducing flame on charcoal, it is colorless, and remains so when quickly cooled. With soda it melts to an opaque-green glass in the oxidizing fire, and on a foil of platina. This test is characteristic of manganese. Oxide of nickel, is not changed by heat; with borax it melts to an orange-red glass, which is almost colorless when cold. In the reducing flame on charcoal this glass becomes gray. This color is caused by reduced metal. With soda, it forms a magnetic powder of metal on charcoal. Oxide of silver is instantly reduced to metal when brought within the flame. It forms a white opaque glass with borax, and is partly reduced to metal in all instances; with alkaline fluxes it forms metal directly when brought in the flame. Oxide of tellurium imparts to the flame a green color, fuses and sublimes; on charcoal it is easily reduced to metal. With borax it melts to a colorless glass in the oxidizing flame; in the reducing flame the glass is gray. With carbonate of soda it acts as with borax, but less distinctly. The oxides of tin are converted into sesquioxide, becoming dirty-yellow in the oxidizing flame; it forms metal after protracted heating on the charcoal support and in the reducing flame. With borax it forms a clear glass, and with alkaline fluxes it is easily reduced to metal on charcoal. Titanic acid, is not altered in the flame when exposed to it; with borax it melts to a colorless glass, which becomes opaque in cooling. In the reducing flame it becomes first yellow, then amethyst, and darkens in cooling. With carbonate of soda it dissolves with effervescence, forming a faint yellow glass, which becomes gray on cooling. It forms no metal on charcoal. Zinc, the oxide of this metal, forms a strong whitish-green flame; it is slightly yellow when hot, but turns white in cooling. With borax it forms a transparent glass, which becomes milky by an intermittent flame; in the reducing flame, it forms metal which is quickly evaporated. Alkaline fluxes do not alter it in the oxidizing flame; it is reduced on charcoal, and in the reducing flame. The metal burns readily and forms a white flocculent oxide, which is yellow when hot.

Operation with Borax.—To perform the operation of smelting so as to produce the described effects, requires some dexterity and skill. We annex for this reason the following notes. The test with borax is generally the most characteristic, and in order to succeed well with it, the minerals must be brought to the highest state of oxidation: the manner of producing this, we shall speak of hereafter. All substances which contain, besides a metallic oxide, also alkaline, or neutral or acid earths, must be melted on the platinum wire, or on platinum foil. The formation of a clear bead of borax is the first object which requires our attention. A single wire of platinum does not form a large globule. We bend, therefore, a platinum wire, and form a small loop at one end; this loop, when heated and dipped into ground borax, is covered with melted borax when heated again, forming a perfectly clear pane of glass over the loop. If sufficient borax is not obtained at the first dip, the operation is repeated until the area of the loop is covered. When the borax is pure, the melted glass is perfectly clear; if any traces of color, or a dimness appears, the borax must be removed from the wire and another trial made with fresh borax. The cause of this impurity may have been on the wire, or in the flame. When, after melting, the glass is found perfectly clear, and in sufficient quantity to form a bead, the borax is separated from the wire by means of a sudden jerk of the hand in which the wire is held. This operation must be performed with quickness; it is done by striking the hand on a table, holding the wire with the melted borax, over a porcelain dish or saucer: the fluid borax will thus separate and fall into the saucer, forming a round bead. This globule of borax is taken in a fine pincers and moistened on one side by the tongue; it is then dipped in the finely-powdered mineral, and melted together with it on the platinum foil or on the charcoal, as the case may be. In many instances it is preferable to attach but a small splinter of the mineral to the bead, because, fine powder, if it is not altogether soluble, is very apt to adhere to the borax and impair its clearness, so that the color cannot be distinguished which it forms with some parts of the mineral. When the test is spoiled by insoluble matter, it is not so apparent with borax as with other fluxes. Some matter is insoluble in borax and will cause dimness or even roughness of the bead. Some substances will form an opaque glass if the flame is not directed properly upon them. If the substance is of such a kind that the reducing flame will cause a milkiness, the very tip of the flame is directed upon it in a regular blast; for the least flickering of the flame will quickly cause the milkiness. This happens particularly with the alkaline earths, and the earths proper, with the titanic acid and tantalic acid. The oxides of iron, manganese, silex, and clay, are not subject to this disorder. The presence of silex prevents, in most cases, the bead from being opaque, even when the substances present would cause it to be so. In all cases it is necessary to use sufficient borax; for some matter is only partially soluble, and will cause the borax glass to become dim, or show no distinct color when in excess. When it happens that the bead is well vitrified, but the quantity of mineral which has been used is so large as to prevent its transparency, the bead may be flattened when hot so as to make it thinner, or it may be taken by the pincers and a fine thread drawn from it. In either case, we shall recognize the color which the mineral imparted to the borax. As this test is a delicate operation, it requires that no objects shall be near which may reflect a particular color to the glass under examination, or that the borax be examined by colored glasses. A lens may be used in these examinations, but in such a manner as not to impart its own colored rays to the glass. The specimen must be, therefore, in the focus of the lens. In all cases it is necessary that no reducing influences should be exerted upon the bead; and to be perfectly safe in this respect, the alcohol flame, and foil support, and a steady blast, are required. Instead of the foil the platinum wire may be used, but it requires more experience.

If the combination of borax and the mineral is thus observed, which must be presumed to have been performed under the influence of the oxidizing flame, either the same specimen may be subjected to the reducing flame, or a new bead may be melted and exposed to that influence. Some of the metals may be exposed on the foil or the wire to the reducing flame of an oil lamp, or a wax or spermaceti candle, particularly those metals which cannot be reduced to the metallic state in that flame, such as oxide of iron, and the oxides of cerium, manganese, cobalt, uran, chromium, titanic acid, and a few others. If the mineral contains oxides which are reduced easily, and may combine with the platinum, such as zinc, nickel, cadmium, lead, bismuth, copper, silver, and antimony, it is necessary that the test should be made on the charcoal support. In all cases of doubt it is advisable to perform the operation on the coal. A good hard coal is for this purpose selected, a small cavity is scraped out, and the reducing part of the flame is directed uninterruptedly upon the bead. A few minutes' blowing is sufficient; the globule is taken in a pair of broad, flat pincers, squeezed flat and removed from the coal, and examined by transmitted light when hot; we may now observe the color as it gradually cools. The flattening of the bead is in all cases necessary, for most of them do not transmit much light when in a thick body. The removal of the bead from the coal is also requisite, because when the globule is permitted to remain on the hot coal, it may oxidize, and alter its color to that of the oxidized bead. In this instance, we always find the coal covered with a film of a metallic oxide, in case the mineral contains any of the volatile metals, such as lead, antimony, zinc, bismuth, and cadmium.

A flux, which is in many instances valuable as a test of metallic oxides, is phosphate of soda and ammonia, often called microcosmic salt. This re-agent does not differ in its action from borax; it causes the bead to be more clear and distinct. The color of it is more readily recognized in those instances where a large quantity of silex is in the mineral, because the silex is not soluble in this salt, and if we select a splinter of the mineral for examination, the silex is found in the centre of the bead as a gelatinous mass. The operation with this flux is similar to that with borax, with the difference that the loop in the wire must be smaller, because the flux does not adhere very well to the platinum.

Operation with Soda.—Alkaline fluxes dissolve earthy matter, and in most cases produce metals from metallic ores. The carbonate of soda dissolves a number of substances quite easily. Some, however, such as silex, titanic acid, and a few other mineral acids, require a rather high heat, and are liable to be absorbed by the pores of the coal support. The manipulation with soda is as follows: the substances must be pulverized, soda as well as mineral; a little of each is taken on the point of a knife and mixed with a little moisture in the left hand, so that the mixture forms an adherent pasty mass. If the mineral is in splinters, which cannot be rubbed fine, the soda is laid around it, forming a cover to it. The mixture is now exposed to a gentle heat on a coal support to expel the water, after which the soda is melted as it flows over the coal. Soon as the mineral is sufficiently hot it absorbs the soda again, which now foams in the process of combination. The fire should not be too powerful at this time, but merely sufficient to melt the soda. If the test is insoluble in soda, the mass does not form a round globule, but appears of an irregular, spongy form. In many instances the mineral may be hardly soluble in a little soda, in which case the addition of a little more soda will cause the formation of a bead. Some substances will, however, not melt together with the alkaline flux. The test with soda depends chiefly on the alterations which that substance forms with minerals when applied in larger or smaller quantities, a description of which would lead us beyond the scope of this work. We shall therefore confine our remarks chiefly to the reducing qualities of soda.

This test shows the minutest parts of metal which may be contained in a mineral, and is in that respect more valuable and correct than the moist analysis. Some metallic ores may be reduced on the charcoal support without the addition of flux; although with the addition of an alkaline flux, the metals are produced with facility. The oxide of tin produces metal on coal in the reducing flame, but with the addition of soda it acts quickly.

When a metallic ore is a combination of metal and such matter as it is difficult to dissolve in soda, the particles of metal produced are often so small that they cannot be recognized by the eye with the assistance of a lens. In all instances the operation is the same; the ore is powdered and the test prepared as described above; when the soda disappears in the pores of the charcoal, more soda is added, and the fire, with the addition of soda, continued as long as a part of the test specimen remains on the coal, or until the coal is saturated with soda, and the matter remains on the surface of it exposed to the reducing flame. When all parts of the ore are thus melted, no matter whether combined with soda or not, the coal is moistened by a few drops of water and the solid contents scraped off by a knife, so that all the soda is recovered. The matter is rubbed in a porcelain mortar to a fine powder with a little water, then the powder is well stirred, and the water gently cast off from the sediment. A repetition of this operation will remove all the light particles of carbon, earths, and all the soda, while the heavy particles of metal remain in the mortar and may be recognized on being flattened by the pestle or any smooth and hard instrument. When the mineral contains no metal which may be reduced in the presence of soda, or if any sulphur is present, or if the operation is ill performed, nothing remains in the mortar. If there is any metal produced, it will either remain as a fine globule, or in the form of a black, heavy powder. The fusible metals form large grains; iron, or metals which require a strong heat for melting, appear in the form of a fine powder. By these means a very small quantity of metal may be detected in a mineral which may escape observation in any other form of analysis. A little tin or copper, not more than ½ per cent of the test specimen, can be detected, provided these metals are not connected with other metals in the same ore; if this is the case, some of the metals generally melt together, form an alloy, and are to be assayed as such. Metals which may be detected by this test are molybdenum, tungstenium, antimony, tellurium, copper, bismuth, tin, lead, zinc, nickel, cobalt, and iron. Other metals, such as arsenic, cadmium, and mercury, are also formed, but these evaporate. For the detection of alumina a solution of cobalt—nitrate of cobalt—is generally used. It has little influence in most of our operations, for which reason we refrain from alluding to it particularly.

Roasting.—If this operation is performed with soda, or any other alkaline flux, the mineral should be brought into the state of an oxide and be free from sulphur. Roasting is a process of oxidation, and may be performed with the assistance of the blow-pipe. The mineral is, for this operation, finely powdered, and this powder is placed in a very shallow cavity upon the face of a piece of hard coal. The blow-pipe is now directed upon it. and the extreme point of the flame performs the process of oxidation. All the sulphur or arsenic is not expelled by this method; a part of it remains in the metal in the form of an acid and is still combined with the mineral. When the smell of sulphur ceases, the reducing part of the flame is directed upon the mineral, in which operation most or all of the arsenic in the form of metal is evaporated. The sulphur being in this process once more reduced, may be now partly expelled in the oxidizing flame. When this process of oxidation and reduction has been repeated different times, and the mineral is well-oxidized on one side, it is turned and the under side exposed to the same operation. After repeated heatings it is put into a mortar, rubbed fine, and again exposed to a similar process of oxidation and reduction as at the first. The liberation of the mineral from arsenic and sulphur is tedious, and requires repeated pulverization and heating; still it is never perfect; some arsenic will always adhere to it after extreme pains have been taken for its removal.

Color of oxides on the coal.—Some of the metals form a characteristic oxide, which is discovered after their reduction and evaporation on the coal. As these oxides are a convenient guide to the quality of the mineral, we insert their most distinct features.

Selenium.—Close to the cavity in the support this mineral forms a gray, iron-colored and glistening filament, which often shows a faint violet or crimson color, and in thin layers has the appearance of blue. The oxidation flame will drive it to any place desired over the coal, but in the reducing part of the flame it evaporates with a blue light similar to that of sulphur.

Tellurium.—This mineral covers the support in a similar manner as selenium in form. The circle around the flame is white, and shows a dark yellow, or often red circumference. The tip of the flame will move it over the coal, the reducing flame evaporates it with a green light, and if selenium is present the fire is bluish-green.

Arsenic.—This metal forms arsenious acid on the support when touched with the extremity of the flame. The ring around the cavity is white, and when very thin it appears gray, particularly that at the greatest distance from the test. The least heat will move it from one place to the other on the coal.

Antimony.—This covers the coal with sesquioxide, which appears white; when thin it appears gray or bluish. It is hardly different from the arsenious acid, but may be recognized by adhering more closely to the test. This oxide may be driven over the coal like the other oxides, by the oxidizing flame; the reducing flame does the same, and shows in the mean time a greenish blue light. This oxide and the metal are not so volatile as the above substances, which distinguishes it from them.

Bismuth.—This metal forms an oxide which covers the coal near the test; when hot it appears of an orange color, which gradually is altered to yellow when cold; if the film is of oxide and very thin it appears bluish. This oxide is still more close to the test than antimony. It may be moved over the coal, but disappears gradually under the influence of heat.

Lead.—The oxide formed by this metal and precipitated on the coal is in all respects similar to that of bismuth; with the only difference that lead is not quite so dark yellow as bismuth.

Cadmium.—This is similar to lead and bismuth. The precipitate on the coal is, after becoming perfectly cold, of a reddish-brown color, which appears in thin layers to be yellow. This distinguishes it from the above metals.

Zinc.—The oxide of zinc adheres more closely to the test than all the above-mentioned oxides. It is yellow when hot, and emits a strong light; in cooling, it changes color to white, and we find it closely surrounding the test specimen. The oxidizing flame does not move it. A drop of cobalt solution changes it from white into a fine green color when heated in the tip of the flame.

Tin.—This metal covers the coal with oxide, which is of a faint yellow color, and emits a strong light when under the influence of the flame; when cold it is grayish-white; it adheres closely to the test specimen. This oxide may be distinguished from that of zinc by its forming a bluish-green with cobalt solution, while that of zinc is bright-green.

Silver.—When this metal is exposed to a strong heat in the oxidizing flame, it covers the coal with a thin film of dark-red oxide. When the silver is alloyed with lead, the first film near the specimen is lead and yellow, but when the globule is more refined, the silver will form its red film exterior to that of the lead film. If antimony is in the specimen, the red color of the silver is more faint than when lead is present. When antimony and lead are present with the silver, the last evaporation of the silver forms a crimson ring around the former oxides.

Sulphurets, *chlorides*, and other combinations of metals and volatile substances, are frequently found native, and as they all, more or less, form white, faint-yellow, or gray films of precipitate on the coal, we should be cautious in deciding on the nature of a specimen until we are convinced of the purity of the metallic evaporations above described. These combinations, to which all the alkaline chlorides, bromides, and iodides belong, are characterized by their film being farther from the specimen, and if brought under the direct influence of a strong reducing heat they evaporate without the slightest change of color. This distinguishes these combinations from the oxides of tellurium and antimony. In all cases it is the surest way to produce metals first, and then evaporate them.

Test on Minerals.—The blow-pipe test is a most convenient operation for the metallurgist; he may use it on minute quantities with perfect certainty as to the result. We insert, therefore, the appearance of various minerals under the effect of the blow-pipe.

Barytes. Heavy Spar.—Sulphate of barytes, when melted with carbonate of soda, forms a fluid glass, which is absorbed by the coal with constant ebullition. Strontium acts in the same manner as heavy spar. We distinguish both by exposing a test without soda to the reducing flame, and transforming it into a sulphuret; when barytes is moistened with muriatic acid, and then with alcohol, it will show no color when heated in burning alcohol, while strontium shows the peculiar crimson color of that salt. If lime is in the specimen it is not absorbed by the coal, but remains on the surface of it, even after a strong fire.

Lime.—Fluate of lime melts to a clear bead by a limited heat, which is clear when pure; if the mineral contains gypsum, heavy spar, or strontia, the bead is opaque. Carbonate of lime, or limestone, is easily recognized by forming quick-lime under the influence of the flame, which shows a brilliant light, and the well-known caustic reaction on the tongue. When melted with borax it dissolves with ebullition, foaming like an organic substance; this is caused by the liberation of carbonic acid. Gypsum and its varieties melt with difficulty in the oxidizing flame. If the test is brought under the influence of the reducing flame it forms sulphuret of lime which smells of sulphuretted hydrogen when moistened. If gypsum is melted together with borax it forms a clear glass when hot; this turns yellow when cold. Gypsum in excess colors the glass and becomes brown and opaque; melted with soda it acts like carbonate of lime, which remains on the coal after the soda is absorbed. All the pure varieties of lime may be tested by these means. When the mineral contains other substances the test is of course modified; we shall mention these modifications in the following pages.

Magnesia.—This substance is not so easily recognized by means of the blow-pipe; it is in all cases necessary to confirm the test by a moist assay, which is beyond the scope of this work to describe. Carbonate of magnesia is converted into caustic magnesia under the influence of the flame, and may then be recognized like lime by its alkaline reaction. Melted with fluxes, magnesia acts like lime.

Alumina.—This mineral is not altered in the flame when pure; it melts slowly with borax, but forms after a prolonged heat a clear glass, which is not altered when brought under the influence of the reducing flame. It also dissolves in microcosmic salt to a clear bead, which distinguishes it from silex. The most positive test is the formation by it of a blue glass with cobalt solution. Soda does not dissolve it perfectly. A mixture of soda and borax dissolves it readily into a clear glass. When the mineral is adulterated with other matter which colors its glass, it is difficult to distinguish alumina; still the addition of cobalt solution will in all cases impart a blue tinge, if this earth is present. Silicates and slags do not show the presence of alumina, even with cobalt solution.

Silex.—This may be discovered in all its combinations by microcosmic salt, on the wire loop. This mineral, when finely powdered and melted with the salt, forms a bead which is in most cases clear when hot, and in which the silex may be discovered as a dark gelatinous centre when light is transmitted through the hot glass. Many of the glasses darken or turn opaque in cooling. It is therefore necessary to examine the bead when hot. If only a little silex is in the mineral or in the slag, it may not be visible, and the moist assay must be adopted to discover it. Soda will dissolve silex and form a clear glass, if the amount of it, or if the silex is not excessive, in all these cases it forms an opaque glass. If the soda predominates to at least four parts of soda to one of silex, the glass formed in the reducing flame is soluble in hot water, from which the silex may be precipitated by an acid, and the subsequent filtration and evaporation carried to ignition.

Manganese.—This metal may be recognized by melting it with a flux of borax or microcosmic salt; the bead is violet, or rose-colored when the quantity is small; if the specimen is brought from the oxidizing influence into the reducing flame, this color disappears; if other metals are in the specimen besides manganese, these will show their own color under the reducing influence of the flame. It is necessary to remove the reduced bead quickly from the wire and cool it as quickly on a cold dish, in order to prevent oxidation by slow cooling, after which it will show the manganese again. If the quantity of manganese is very small and not recognizable in borax, a splinter of saltpetre may be added to the melted bead, which will make the hot test foam, and that foam will show the amethyst color in the oxidizing flame. Very small quantities of manganese, such as one thousandth part in a mineral, cannot be discovered by the above means; we may detect that in the following operation. The mineral when finely powdered is mixed with 2 or 3 parts of carbonate of soda; or rather, 1 part mineral, 1 part saltpetre, and 2 parts soda, are melted together on platina foil in the oxidizing flame, in which the mineral will so far dissolve, that the most minute particle of manganese will appear. It imparts a green color to the melted soda, which is often found to be bluish green; this color it retains after cooling. If the mineral contains cobalt and silex, the color is always blue; but if the silex is removed by some means, the green color may be observed again. In this operation sulphur, arsenic, and other volatile substances, must be separated by roasting before the mineral is exposed to the test.

Zinc.—This is soon discovered when the mineral—it may be a sulphuret or an oxide—is mixed with carbonate of soda and cyanide of potassium, and exposed to the reducing flame. The characteristic film of oxide is quickly found on the coal.

Cobalt.—When a mineral containing cobalt is oxidized and melted with borax or microcosmic salt, a blue glass is formed, which if the quantity of cobalt is large, often appears to be black, particularly in a round bead. This color is equally distinct in the oxidizing and in the reducing flame, and may be brought forward if the mineral contains much other metallic oxides, by exposing it to a strong heat in the reducing flame, which will expel most of the other oxides, but not that of cobalt. Iron and manganese are an exception to this rule, and may be exposed to the oxidizing flame, in which iron is colored the least.

Nickel.—Most of the minerals which contain this metal, are a compound of various substances, which, however, does not much interfere with its detection. The test is first roasted in a glass tube which shows arsenic; it is then roasted on the coal; this removes the other parts of arsenic and volatile substances. Melted with borax it shows the peculiarity of the oxide of nickel, which is dark violet when hot and changes to red brown in cooling. If this glass is melted in the reducing flame, some of the oxide is converted into metal and adheres to the outside of the glass, where it may be recognized in small globules by the assistance of a lens. Sometimes the nickel is in a metallic form; and if no other metallic oxide is present the glass is colorless. If iron or cobalt is besides nickel in the mineral, the remaining glass of course is colored by their oxides. If the roasted mineral is melted with soda and borax and contains arsenic, a compound of arsenic and nickel is formed. Nickel is attracted by the magnet, and the globule of metal may be tested by that means.

Iron.—Any specimen which is to be tested for iron should be well roasted before it is melted with flux, in order to remove all volatile substances. The mineral is then melted with borax, which shows in the oxidizing flame the yellow-red color of the oxide, and turns in the reducing flame bottle-green. If other metals, such as copper, lead, antimony, &c., are present, they are reduced in the flame, and the glass remains bottle-green. If the color is bluish, it indicates the presence of cobalt, and if the green color is not distinct, a small particle of metallic tin added to the glass will soon make it so. If copper is present, it is often a tedious operation to bring the metallic copper out in the reducing flame. Perseverance will however succeed in all cases. Are metals present which cannot be removed by the united action of borax and reduction, the addition of metallic lead will soon remove them and show the peculiarities of the glass of iron. Iron is found in most of the minerals, and in examining these we must be always prepared to meet with it, and examine for it particularly. Manganese and iron are generally found together, and the first often hinders the latter from showing its peculiarities; the glass is red in the oxidizing and red in the reducing flame. If, in this case, we add a little metallic tin to the reducing bead, the iron is converted into magnetic oxide and will show its peculiar green color. Iron cannot be reduced to metal before the blow-pipe, while all other metals except manganese can be; thus far it is readily detected.

Cadmium is volatile and cannot be recognized but by its oxide it is treated and behaves like zinc, from which it is distinguished by its brown color, which may be recognized if the mineral contains but one or two per cent. of cadmium.

Lead.—A test on lead is very easily made. It is recognized in very small quantities in its peculiar oxide, which spreads in a film over the coal when treated in the oxidizing flame. Is the mineral mixed with zinc or antimony, it may cause the color of the oxide of lead to be more faint than it otherwise would be, but it never is blended so much with other substances as not to be recognized. If lead is combined with volatile matter such as sulphur, and other metals at the same time, it is melted with a little borax in the reducing flame. The metal evaporates and shows its oxide on the coal. The remaining glass will show the peculiarities of the metallic oxide in the lowest state of oxidation. Minerals which contain lead combined with strong acids, such as sulphuric acid or chlorine, must be smelted with carbonate of soda; this will show the film of oxide on the coal. If metal is formed in this operation, it may be evaporated under the influence of the oxidizing flame.

Bismuth.—This metal is discovered by melting those substances containing it with borax, in case sulphur is present; but when the mineral is free from sulphur and oxidized, it is melted with soda: in the reducing flame the bismuth is evaporated, and recognized by its peculiar oxide on the coal. If, in the mean time, lead is melted with bismuth in the specimen, it is difficult to detect the latter, because the oxide assumes almost the color and behavior of the oxide of lead. It is light and changes its color very little in cooling. It is difficult to find bismuth when other metals, such as lead, antimony, copper, &c., are present; and in this case the better plan is to resort to the moist analysis.

Uranium.—This metal is so similar to iron under the blowpipe flame, that it can hardly be detected in a compound mineral.

Copper.—This metal is very easily recognized if present in a test specimen. When a specimen is first exposed to roasting in the oxidizing flame on coal, and then melted with borax in the same fire, the resulting glass will show the color of the oxide of copper. After the glass has been cooled, and melted again in the reducing flame, it assumes a red color and becomes opaque if no metallic copper is formed. On the contrary, when it is formed, the glass is transparent or colored with oxides which cannot be reduced. This test for reducing the oxide is a safe and sure one, but it is sometimes difficult to produce it. When to the green glass of the oxidizing flame a little metallic tin is added and the test quickly exposed to the reducing flame, it is converted into protoxide, and shows either a red color, or if much copper is present appears black in the mass; but in small threads and splinters it shows the red color in great beauty, especially in case no other metallic oxides are present which impair that color, such as iron or uranium, antimony, and others. When other metals are present, it is advisable to roast the specimen and expel all the volatile metals. This is the more easily accomplished, as copper is very permanent. The changing color in the borax glass may now be observed to more or less perfection; it is always distinct. When a large quantity of copper is present, it is the quickest operation to reduce the oxide by melting it with soda and producing metallic globules, which in most cases are formed in the reducing flame by the aid of borax. Small quantities of copper, such as one per cent. in the mineral under examination, cannot be reduced to metal and must be detected in the colored glass.

Silver.—Metallic silver is easily recognized when pure. If it is combined with other metals which are volatile, it is generally evaporated with these metals, and shows on the coal its oxide. Antimony, arsenic, and quicksilver, may be evaporated in the oxidizing flame, without evaporating silver. Silver is so easily detected by the moist analysis, that it is hardly advisable to make a trial for it under the blowpipe. It may be advantageous with a mineral which contains chloride of silver, which when melted with soda yields its silver readily. As silver is, in most cases, present only in small quantities, the better plan is to make a crucible assay, which always secures a safe result.

Mercury.—Quicksilver cannot be detected before the blowpipe; it evaporates so perfectly that no traces can be found of it on the coal. A mineral which contains mercury is rubbed with soda, and this mixture is exposed in a long glass tube, or a glass retort, to the heat of a spirit-lamp. The quicksilver soon makes its appearance, and condenses in fine metallic globules on the cold parts of the glass. When a test of mercury cannot be made by other means than the blowpipe, we mix the mineral with a little common salt, and, if it contains sulphur, with soda and a little salt. On exposing this mixture to the reducing flame, a white sediment is formed on the coal, which consists of calomel or subchloride of mercury. This test requires experience in order to distinguish mercury from other volatile salts.

Platinum, and the platinum metals, cannot be separated one from the other under the blowpipe. These metals when melted with borax show sometimes colored glass, which is caused by admixtures of other metals, such as iron, copper, &c. When a particle of metal resists the strongest fire of the blowpipe without oxidation or melting, we may expect it to be platinum. In order to test it finally, it is mixed with a little pure lead, and melted with it. Melted lead will dissolve platinum, and may be partly evaporated. The platinum will always retain a part of the lead. In case no gold is present, the strongest heat will not remove all the lead. If in this case we add a little gold to the test and melt it again, the lead will be evaporated, and the white platinum will assume a somewhat yellow bright color; this is imparted to it by the gold. The gold cannot be separated from this alloy but by solution and moist analysis.

Gold.—This metal is always recognized without testing it before the blowpipe; but if we are doubtful as to the identity of the metal, we may melt it with borax in the oxidizing flame in which all other metals but gold will be altered. If silver is mixed with gold in a mineral, it will remain in combination with the gold. Should it happen that a test shows signs of the presence of gold but does not melt readily, the addition of a little lead to it will melt it; the latter, however, may be driven off in the reducing flame. If a grain is thus obtained which to all appearance is pure metal, that is, gold or silver, but is bright so as to indicate the absence of gold, we may observe the latter by throwing the globule on a white porcelain dish and moistening it with a drop of nitric acid. If the globule is pure silver, it will dissolve and retain its white color. If it is mixed with gold, it will soon turn gray, or be covered with a black film.

Tin.—This metal is soon detected in minerals which contain tin chiefly, but not so in those which contain other fusible metals.

Sulphuret of tin when melted on the coal support under the influence of the oxidizing flame, evaporates the sulphur at first, which is recognized as sulphurous acid; subsequently the metal evaporates and forms a white film on the coal, which cannot be removed by the fire, and is characteristic of tin. When any compound of tin and refractory metals, such as copper and iron, is melted with borax, the tin will form metal in the reducing flame, which may be recognized with the aid of the lens.

Antimony—This metal acts like tin before the blowpipe; but we may distinguish it from the latter by exposing the test in a glass tube to the heat of a spirit-flame, which, forming an acid and an oxide of antimony, condenses in the cold part of the glass tube, and is recognized by the dirty-yellow color. It is difficult and requires experience to distinguish antimony from arsenic, tin, and zinc, on the coal support. The oxide of the first is not so permanent as tin, but more so than arsenious acid, and it may be distinguished from zinc by the changing color of the latter. In all instances the test in a glass tube is the most certain of success, because if the specimen contains all the fusible metals, antimony may be found and separated from the others. If we put the test in one end of the glass tube and heat it at first gently over the spirit-lamp, holding that end of the tube containing the specimen lower than the other, a current of air will draw through the tube. Sulphur will evaporate first, in case the test is a sulphuret. It is carried off by the air, and forms no sediment; then follows arsenic, which may be driven higher in the tube in case it condenses too low; the next is oxide of antimony, which cannot be affected so easily by heat; other metals will not evaporate under this heat. In all cases where this test is applied it is advisable to roast the specimen and operate upon oxides.

Titanium.—This metal is in most instances under the form of titanic acid in the minerals, and can be recognized as such. Such minerals melt readily in borax, but the color of titanium cannot be observed. The glass is yellow, and cannot be altered in the reducing flame; titanium is thus distinguished from iron. Microcosmic salt dissolves it with difficulty, and forms a white opaque glass, which when brought into the reducing flame, with the addition of a little metallic tin, shows the red oxide of titanium. The darker this red color is, so much the more titanium may be supposed to be present. Wolframium acts in a similar manner, without the addition of tin. Metallic titanium appears often as a red film on the slags from an iron furnace. It resembles metallic copper. It may, however, be distinguished by melting it in borax in which it hardly dissolves, while in microcosmic salt it dissolves readily. This titanium always contains iron, and shows the colors of it in the glass bead.

Chromium.—Borax or microcosmic salt, melted together with the specimen, form a glass of a bright emerald-green color when perfectly cool, provided the mineral does not contain lead or copper. This color is very beautiful after exposure to the reducing flame. If lead or copper is present the color is totally destroyed in the reducing flame. It is, therefore, in the oxidizing and reducing flame where we distinguish chromium. When a little chromium is present in a large quantity of other minerals, the specimen is rubbed with three volumes of saltpetre, melted on the wire loop to a vitrified mass, and then dissolved in boiling water. Chromate of potash is here formed, which is dissolved, and the clear liquid, when decanted, is tested by saturating it with acetic acid and putting into it a splinter of clear acetate of lead. If any chromium is present, it will color the crystal and form the well known chromate of lead.

Tellurium.—This substance may be detected by simply directing the flame upon it. It will form the film of the oxide of tellurium on the coal. If any smell is produced by the application of heat selenium may be present, provided no sulphur is indicated. The film formed on the coal is characterized by a red ring around it, and it entirely disappears when touched by the reducing flame, showing in the mean time a bluish-green light. If lead or bismuth is present in the mineral, it is necessary to melt it with borax, and heat it under the influence of the reducing flame; these metals will then evaporate, and tellurium only appears on the coal. A test of tellurium is somewhat difficult, because in most cases selenium is with it. The film on the coal is not distinct, and it may be preferable to make the test in the glass tube. It is in this case treated as antimony, and a limited heat shows a copious white smoke, which condenses on the glass. This white film is melted by the application of the spirit-lamp to clear globules, which also adhere to the glass, and which may be recognized with the aid of a lens. If selenium is present, these drops are also formed, but they are then not quite clear or transparent.

Arsenic.—If arsenic is present in a mineral it is quickly recognized on bringing it into the reducing flame of the coal support. It emits a smell similar to that of garlic or phosphorus, which is characteristic, but often faint on account of the presence of other metals. In the glass tube it becomes volatile more readily than other metals, and may be driven to any place in the tube by the heat of the lamp. The latter is arsenious acid and does not smell.

Selenium.—This substance is easily detected if no tellurium is present. In all cases we find its presence by heating a splinter of the mineral on the charcoal, and bringing it to the nostrils; a characteristic odor of decaying horse-radish is emitted, which is not observed from any other matter. It is necessary that the test should be red hot.

We have been thus far particular in treating of blow-pipe tests, not because they are of prominent practical value, but because they are peculiarly suitable to detect substances which cannot be found by a crucible assay, and which are frequently of considerable influence in smelting operations. The following materials, necessary to make blow-pipe assays, and by which a trial on a mineral may be made at any time and place, can be put up so compactly as to be carried in the pocket, viz., a candle and a piece of coal, the blow-pipe, borax, soda, saltpetre, microcosmic salt, cobalt solution, a pair of pincers, the platina-wire loop, and a bit of platina foil, a piece of glass tube, a lens, a small hammer, and a very small glass or agate mortar. If a magnet, knife, file, a porcelain dish, a glass test tube, and a little nitric acid are added to the apparatus, it will be more complete. In all instances a little pure metallic lead, and a little tin, should be at hand. The whole collection may be fitted into a small box, which renders it portable and convenient.

We omit alluding to the blow-pipe tests on acids, chlorine, phosphorus, bromine, iodine, fluorine, carbonic acid and similar substances, because these are of little practical importance. These substances serve chiefly to increase the fluidity of slags, and are of no further interest. One half of one per cent. of phosphorus may spoil good iron ore. The most delicate blow-pipe test cannot detect less than three per cent in a mineral. It is therefore of not much use to know if any phosphorus is present in iron ore, since we cannot approximate to the injurious quantity. The case is similar with other minerals.

Crucible Assay.—The blow-pipe assay is never much more than a comparative test. The actual quantity of metal present is found with much labor, and there is always some uncertainty in the result, because the test is made on a small quantity, never more than half a grain. In order to make an assay at the same time as to quality and quantity, we adopt smelting in a crucible, in which we expose at once 500 or 1000 grains to the test. In many instances it is necessary, in order to make a perfect assay, to use re-agents and solvents in the moist way. We shall notice each case in the course of these investigations. The dry assay affords the advantage of an exact determination of the weight, which is with most of the metals more correct than in the moist analysis. The earthy matter is easily removed, and very minute quantities of metal may thus be detected, which often escape observation in the moist assay. The results of the dry assay are quickly obtained, and are cheap, and very uniform. They are, therefore, best qualified for determining the metallic contents of an ore. It affords, besides, the advantage, that all the smelting operations on the large scale may be imitated in the crucible, and the quantity and nature of the fluxes decided on in them. Experiments of the latter kind are very expensive in the large furnaces, but they may be done cheaply and effectually in the crucible.

Instruments.—A good balance, or, where precious metals are to be weighed, two balances are needed—one a strong balance, on which at least one thousand grains, and from that to twenty, may be weighed, and another, a small one, on which from twenty grains to one tenth of a grain may be determined. J. P. Duffey, of Philadelphia, manufactures balances of a superior kind. The weights used in determining the contents of metal in a specimen of ore are arbitrary, and may be either troy weight or avoirdupois—the latter is preferable when the assay is made for practical use. When the pound avoirdupois is divided into 10,000 parts—instead of 7000 grains—which may be called mills or mill-grains, we obtain at once the quantity of metal in the ore in a decimal, and the weight is so near the real grain as not to show too much difference for comparison. Gold and silver must be weighed by troy weight; and as the present division of the pound into 5760 grains is generally adopted, it may be advisable to retain this weight, because it facilitates the valuation of the ore. All the ore is bought by avoirdupois weight; this does not conflict with the result in weighing an assay in grains of troy.

Mortar.—This instrument is required for crushing and pounding the mineral. In the majority of cases an iron mortar is sufficient for this purpose. In some instances a hard agate mortar is required, because when the mineral is hard, the quantity small, and the amount of iron in an ore is to be ascertained, it may happen that iron is rubbed loose from the mortar and passes into the assay. If it is found necessary to grind the mineral very fine, it is rubbed, which produces a fine powder; when the pounded mineral is to be in the form of sand, the piston is used with a vertical stroke, with little mineral in the mortar at a time, and without rubbing; this will cause the mineral to be in grains. If a mineral is very hard, we heat it to redness, and throw it suddenly in cold water; when it adheres in the mortar, it is mixed with pure sand, which will prevent it. When arseniurets or arsenious minerals are to be pounded, the mortar must be covered by a cloth, to prevent the operator from inhaling the dust from the mineral.

Sieves.—These may be of brass or iron wire. In many cases silk sieves are used, because the first are not sufficiently fine. A good fine brass-wire sieve is in most instances sufficient. If a powder of a certain uniform grain is to be produced, we make use of two or more sieves of different fineness, driving the fine dust through the finest sieve, and afterwards using the coarser one. If the dust of the mineral is poisonous, we cover the sieve above and below with strong paper, and a cloth, to prevent the flying of dust.

Washing.—Most minerals contain impurities which it is not necessary to subject to smelting; these are generally light, and may be removed by washing, such as clay, lime, or magnesia, from sulphurets, or from heavy crystalline particles. The powdered substance is thrown into a dish, or iron pan, clear water poured over it, and the whole well mixed by hand. After a few seconds rest the heavy matter subsides, and the muddy water is gently poured off. This process is repeated until the water flows off perfectly clear. Oxides of iron and lead, also sulphuret of zinc, cannot be washed in this manner. If we want to perform the operation of washing with great precision, we make use of a glass jar, or a cylindrical and clear glass bottle. We stir the mineral and water well together, and after a time we draw off the liquid by means of a syphon. We may thus take as much water and as low down as we choose; and as the strata of the different substances in the order they descended are visible, we may remove any kind of matter which we desire to separate from the rest. It is of no use to wash a mineral if we desire to know the exact amount of metal in it, for in all cases of washing, some of the mineral is lost. If a powder of exceeding fineness is required we may obtain it by rubbing it with a little water in a porcelain mortar, after the mineral has been run through a sieve and washed.

Calcination.—Minerals which contain volatile substances are generally calcined in order to remove these substances. We heat iron and zinc ores to remove water from them, and calcine iron ore, lead, zinc, and limestone to expel carbonic acid. We likewise ignite sulphurets and arseniurets to liberate the mineral from these substances. In most cases it is necessary to observe the loss in weight caused by this operation. Water will escape by applying a gentle heat, but if much clay is present it adheres tenaciously to the mineral. Carbonic acid requires strong ignition and the presence of carbon to remove it; sulphur and arsenic act like carbonic acid, but cannot bear so much heat at first. Coal and wood require a strong red heat in a partly closed vessel to remove their volatile substances. Calcining is an operation which is most conveniently performed in a crucible, because no stirring of the mass is required. If the substance is affected by coal, we are to select a Hessian or clay crucible; and if it is affected by silex or clay we select a plumbago pot. When the mineral cannot bear the presence of atmospheric air, such as the evaporization of bitumen from coal, we fill a small crucible with the substance, cover it, and as the cover cannot be made to fit quite close, we insert this crucible in a second and larger one and cover that also. The heat of an air furnace is generally sufficient to perform this operation.

Roasting.—This operation is always performed in the open air. The object is to bring oxygen in contact with the mineral in order to oxidize it, or to remove those volatile substances which are of no use in the assay, or cause it to be incorrect. This process is best performed in the muffle, which apparatus will be described presently. The substance, well powdered, is laid on a flat dish of unglazed earthenware, for which a piece of a broken flower-pot is best adapted; if this cannot be had, the glazing of any other fragment must be removed by soaking it in water, and exposing it to a sudden heat, which will remove the scale. The mineral, when simply a hydrate, is exposed to a strong red heat, and stirred by means of an iron rod. In these cases, there is no apprehension of melting the mass, and the process is accelerated by the heat. When sulphurets, or such substances as are liable to melt, are to be roasted, the heat must be very limited at first, and never so high as to melt any of the particles. In these cases, and in all those where iron may injure thetest, a glass rod provided with a wooden handle is used as a stirring instrument. If it happens that particles of the pulverized mineral melt, it may still be exposed to a strong heat, in order to drive off as much of the volatile matter as possible, and then pound and sift the substance once more. If the melting is not prevented in the subsequent operation, the material must be pulverized again, in fact as often as signs of melted particles appear. Most substances are not so fusible in the form of oxides as in that of sulphurets, arseniurets, and chlorides, and we may therefore increase the heat as the oxidation progresses. Some substances require the addition of carbon to remove the last traces of volatile matter; such are arseniurets, sulphates, and nitrates; in fact the addition of a little charcoal powder at the end of the operation is always advantageous; after it is consumed a strong heat assisted by much stirring must be applied. In some instances the addition of a little carbonate of ammonia is advantageous; this liberates sulphuric acid and chlorine, which often adhere obstinately to the mineral. This ammonia should be applied in solution. The mineral is therefore removed from the fire, cooled, and moistened with the solution, it is then dried and roasted again. Some minerals will melt in the lowest heat which we can apply, such as sulphuret of antimony; these may be mixed with pure granulated quartz, and roasted with it. The quartz is subsequently removed by washing, which is easily performed when the oxide is fine and the quartz coarse. Some oxides are volatile, and a high heat must be prevented at the end of the operation.

Melting.—We melt ore instead of exposing it to roasting or calcination, in order to prepare it for reduction. This is frequently done with copper ore; or we melt it with some flux which will show the relation of the ore to the flux; in case the composition of the ore is unknown, we approximate by these means the proper treatment for reduction. We melt ore with borax in a clean silicious crucible, to observe the glass it forms with the borax, or with soda, and by these means detect the presence of such metals as cobalt, chromium, manganese, &c. By referring to the blow-pipe tests we find the characteristics of the glasses, which are here produced on a larger scale, and are of course more suitable for observation. A mineral is melted by itself to ascertain if it loses in weight by the evaporation of volatile metals, or to observe the flame in the crucible. The color of the flame indicates the presence of one or the other kind of metal, as it has been explained in the blow-pipe test. In the mean time we condense some of the vapors on a cold iron rod to observe the color of the oxides, which are similar to those produced by the oxidizing flame of the blow-pipe. We melt also a mineral with other oxides or a metal in order to observe the effect produced, either for the purpose of showing the color of the glass more distinctly, or to prepare the test for reduction.

Crucibles.—The process of reducing an ore to metal is performed in crucibles or pots, of which we employ two distinct kinds; the one is the clay crucible which is free from all carbon, and the other is the plumbago pot. Cast iron crucibles, or retorts of iron, are also used, but not so frequently as to form a particular object for description. Clay crucibles are not, as yet, manufactured in this country; we use chiefly the well-known Hessian crucible imported from Germany. These are perfectly well adapted for most assays, and are cheap and durable. Plumbago crucibles are manufactured in this country to great perfection, and equal to the imported ones; the price of these is higher than that of the Hessian pots; their use is very limited in the assay. We are under no particular necessity of using this crucible at all, because we can line a clay crucible with fine coal dust, which is equal in effect to the plumbago of the black pot. In some instances we need crucibles of pure coal; these may be made of a piece of strong charcoal and are then inserted into a Hessian crucible. Generally, a Hessian crucible is filled with finely powdered charcoal, slightly moistened and firmly rammed into it until quite full; a hole is then carved or scraped into the middle, which forms the pot. In other cases, we moisten the fine coal dust slightly with gummy water, a solution of starch, oil, salt water, or a weak solution of carbonate of potash or soda. The paste thus formed is in either case rubbed over the inner surface of the clay pot; a lining about ⅛ of an inch thick is thus formed, which is firmly dried, and forms the coal crucible. The best lining for a crucible is formed of dust from soft coal, such as willow, poplar, or buttonwood coal. The powdered coal is moistened with water and firmly driven in an iron pot which has a form similar to a clay crucible; the cavity is scraped out by means of a knife, and the inner surface finely polished by a glass rod. This lining may be dried in a red heat, provided the caution is taken to fill the crucible with fine dry coal dust and cover it with clay. After burning, it forms a strong pot of a close grain, so that the smallest particle of metal may be detected in it. This coal crucible is inserted in a clay pot and used with it. It is made ¼ and from that to ½ of an inch thick in the sides. Good coal-lined crucibles are indispensable in some assays. Wrought-iron crucibles or retorts are frequently in use. The latter may be made of wrought-iron pipe, bent, and one end stopped up by an iron plug.

Crucibles must be provided with a cover in order to protect the test against the influence of coal and atmospheric air. This cover should have a handle on its upper side, and fit closely to the crucible. In case no regular cover can be obtained, a slab of fire clay, or even a piece of fire brick may be used as a cover. A good coal, that is, a knotty or spongy piece of coal, may also serve as a cover, but in most cases these throw off splinters which fall into the melting mass and frequently spoil the whole assay. If the mineral is of such a nature as to boil when heated, we do not cover the crucible at all, and prevent the dropping in of coal by setting around it such coal as will last until the assay is completed. When crucibles are put on the grate-bars of a furnace, the draft of cold air will prevent the bottom from getting hot; if we raise it above the grate-bars and the coal is below it, the bottom heats quickly; but the coal above, in consuming will often sink on one side a little more than on the other, which causes the crucible to incline and spill its contents. A crucible is generally placed on a foot-piece formed of fire-brick. This is from three to four inches high, and elevates the crucible above the grate-bars. When the heat required for the assay is not very high, an old crucible, set in an inverted position on the grate, may serve as a foot-piece. If a very high and a protracted heat is required to melt the test, or finish the assay, the foot-piece must be made of good fire-clay, so as not to melt and precipitate the crucible. The material of the test—that is, ore and fluxes—by being pressed into the crucible, becomes sooner heated. If the test is of such a nature as to melt easily and boil much, it is not advisable to press the mass too strongly, as it may cause the crucible to crack, and spoil the assay. Moisture of any kind, such as water or oil, &c., is objectionable in the crucible; it invariably causes a broken pot. The fluid hardens the mass, which, in expanding more than the crucible, causes it to break.

Crucibles are bad conductors of heat, and it requires a long time for it to pass through a pot. High temperature causes the heat to penetrate a little faster than otherwise, but this is of small benefit. It is therefore of no use to expose a crucible to a high heat at once; the better plan is to commence smelting at a low heat and gradually increase it. All crucibles should be gently dried, so as to expel the water; and any pot which has not been thus dried is liable to crack on being exposed to fire. A crucible is set firmly in the furnace, upon its sole-piece, while the furnace is cold. The coal is then carefully placed around it and the fire kindled, so that the heat may increase slowly; no draught or blast is applied during the first half or three quarters of an hour. If a test is sufficiently melted, and the assay considered as completed, no fresh coals are applied. The coal is burned down so far as to make the crucible accessible by the tongs, and it is removed from the fire; when the sole-piece adheres to the crucible, it is removed also with the pot, and broken off when cold. A pair of blacksmith's tongs with flat fire ends is used for withdrawing the pot from the fire, or a pair of basket tongs which touch the crucible outside only. In most cases a pair of fire tongs is all-sufficient for the removal of a small crucible, if it is not quite filled with the test. When the crucible has been exposed for an hour or less time, to the influence of heat, it is uncovered and examined. If the ebullition has ceased, the pot is covered again and the fire urged, but no coal is added to it. When the fire burns quietly we may hear the noise of ebullition and regulate it accordingly. Some tests, those which contain carbonate of soda or potash, never cease their ebullition, at least not before the smelting of the ore is completed, and we are compelled to remove them before they are settled. When the crucible is cold, it must be broken to obtain the metal button which is found at its bottom. If the crucible is lined with coal, it is cautiously removed by means of a knife, and the lower parts of it around the button are carefully examined for metallic particles.

Furnace.—In almost all cases, a furnace such as is represented in fig. 94, is sufficient for assaying any kind of ore. This furnace is built of fire-brick, particularly the interior of it; it is about 3 feet high, and the ash-pit is one foot deep. This is best laid on a smooth brick floor. In case a crucible breaks, or the contents of a valuable assay are spilled, they may thus be recovered by washing the ashes of the ash-pit. The furnace is about 2 feet high, and from 12 to 15 inches square, according to the kind of fuel used. It may be erected near any chimney, which is at least 15 or 20 feet high. The inclined top of the furnace is covered by a plate of sheet-iron, fastened to a wrought-iron frame, which slides easily, or may be easily removed with a pair of tongs. The flue of this air-furnace leading to the chimney is about 6 inches square; the size of the flue depends on the height of the chimney, or the draught in it. The grate consists simply of some wrought-iron loose bars, which may be removed at any time. Any air furnace in which brass is melted in founderies, is adapted for an assay furnace.

FIG. 94.

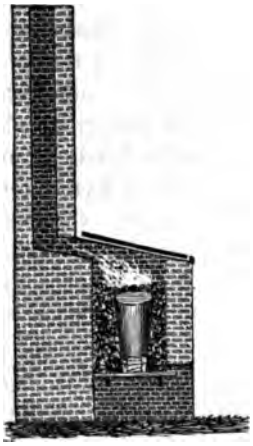
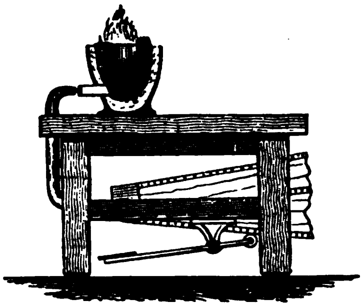


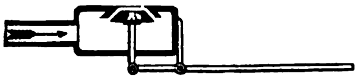
FIG. 95.



Blast Furnace.—Recently a blast furnace for assaying has made its appearance, which is superior to all former ones. In fig. 95 the furnace, and table upon which it rests, are represented. The table is of a common form, strongly built; the bellows may be of the form of a smith bellows, or any other we choose, provided it produces sufficient blast for a vivid combustion. The furnace is simply an iron pot, of a round form, representing a vase, or the interior of a blast-furnace hearth for smelting iron. This iron pot is lined in the interior with fire-clay, about one inch thick, to protect the cast-iron cloack against the heat. In the lower part of the furnace is a tuyere, consisting of a brass pipe which fits closely in the iron pot, but does not reach through the clay; this pipe is two or three inches long, and from half an inch to one inch in diameter. The furnace is movable on the table, and may be brought more or less closely to the nozzle of the bellows-pipe, which is fixed. In bringing the furnace so close to the nozzle as to push the latter, which is about half the diameter of the tuyere-pipe, into it, the draught is weakened in the furnace. The strongest fire is produced when the extreme end of the nozzle and that of the tuyere are in one plane, as shown in the engraving. On such a table two or three furnaces, suitable for small or large crucibles, may be used. These tables and furnaces are very convenient. The operator has the regulation of the heat perfectly in his power, and much coal may be saved in their use compared with the air-furnace.

Instead of the above-mentioned furnace, a common smithy may be used. Those fires which are supplied with Porter's patent tuyere are the best. This tuyere is represented in fig. 96. A conic valve which is movable from below, by a lever, causes the tuyere to pass more or less blast, by diminishing or increasing its size. Over this tuyere, or any other, a small furnace of brick may be erected and used as the one above, held together by surrounding ashes.

Fig. 96.



There is quite a variety of furnaces in use, which, however, are all based upon the principle of producing a lively heat, and put it in the power of the operator to make more or less heat at any time. For assays generally the air-furnace, fig. 97, is the most convenient; and if there is any useful improvement, it consists in the addition of a blast below the grate. This will enable us to make strong heats in a short time, which is required in some assays, such as iron. The nozzle of a pair of common smith's bellows, when directed into an aperture leading through the brick wall under the grate, will produce the desired effect. The entrance to the ash-pit is in this instance closed up, either with an iron plate, or walled up temporarily with bricks. In most cases, the air-furnace is preferable to the blast-furnace; and if we provide it with a good chimney, it is the best in all instances. In assaying, it is of little use to make a rapid fire upon a cold crucible, for we may melt the crucible before its contents are hot. In melting metals, or alloys, a blast-furnace, such as that represented in fig. 98, is useful, because metals conduct the heat very quickly and are soon melted, which is not the case with ores. In all assays it will sometimes happen that a crucible is broken by the heat, the contents flow down, and a blast-furnace is filled with the slags, which are not so easily removed from the fire-pot. The air-furnace is superior to the blast-furnace, because some of the loose grate-bars may be removed, the formed clinkers will drop in the ash-pit, and such an accident will not delay the smelting of another test. An air-furnace may be used a day, or longer, without obstructing the grate by clinkers; a blast-furnace is soon so filled by scoriæ as to cause an interruption of the operations. Three or four hours' smelting in a blast-furnace fills it with clinkers. An assay causes in most instances the use of two hours' fire; some may be made in a shorter time, but not usually. It is no advantage if we apply a strong or too quick heat; not much time is saved thereby, and the danger of a failure, by breaking the crucible, is increased.

FIG. 97.

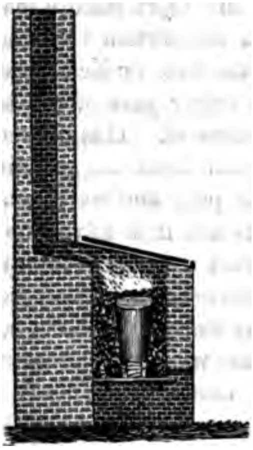
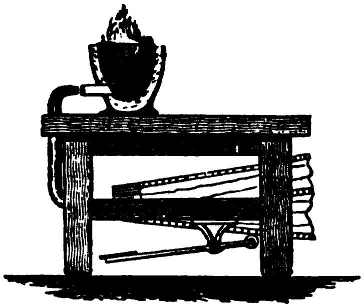


FIG. 98.



Assays are not often performed on more than 1000 grains of ore, which requires a crucible about four inches high and three inches wide. An air-furnace of eleven or twelve inches square, may take three or four such pots, if the fuel is coke or anthracite. Charcoal requires a larger furnace when more than one or two crucibles are to be inserted. In order to smelt more than one assay at a time, it requires a uniformity of minerals; we may smelt four lead assays at once, but not iron and lead at the same time. The crucibles must be firmly set on their foot-pieces, so that one after the other may be removed. When anthracite is the fuel, no foot-pieces are required, provided some attention is paid to the filling of coal and the position of the pots; in that case a layer of coal is laid over the grate-bars, and the pots posted upon the coal; a further addition of coal is then laid around and between the crucibles, and fire is applied from above. Foot-pieces prevent the heat from reaching the bottom of the pots, which is advantageous for lead, antimony, and assays which require little heat and of which the metals are volatile. Assays of iron are more readily made without sole-pieces, because it requires a hot bottom to be successful. All assays work better when the fire, or heat, draws gradually downwards; that is, when the upper part of the test is melted, while the lower part is not softened. This prevents ebullition, and consequent loss of mineral from the crucible. The fire is, therefore, kindled above the pot; and even when assays have been made and the furnace is hot, it is advisable to drop the hot coal into the ash-pit, and start the next operation with fresh and cold coal. The fire is started slowly, that from one half to three quarters of an hour may elapse before the heat reaches down to the grate bars. The plate which is commonly used for shutting the top of the furnace closes the ash-hole to prevent the access of fresh air to the fuel, and in the mean time diminishes the draught so far as to limit it to the absorption of the gas from the furnace. When the crucible and furnace are by these means slowly heated, the furnace cover is put on, and the draught increased to finish the smelting in the shortest time. The filling of coal is so regulated that when the assay is finished, the coal is mostly consumed. There is no difficulty in managing charcoal to burn down to the grate-bars; it is not so easy with coke, and almost impossible with anthracite coal; of the latter, some always remains on the grate-bars. Many coals contain sulphur, or pyrites, which in burning forms oxide of iron, which combines with the material of the bricks and that of the pot. If the amount of iron thus liberated is great, it often causes the destruction of the crucible, because it melts the mass and forms a fusible slag with it. It is therefore advisable to select pure coal, free from sulphur, for assay operations.

Cupel Furnace.—In order to separate precious metals from others, the cupel, a flat porous crucible, is used. To heat this, a furnace of a peculiar form is required. In some instances the furnace is portable and the fire urged by bellows; for our purposes it is found preferable to employ a stationary furnace, which is cheaper and equally effectual. The essential part of a cupel furnace is the muffle. This is a box in the form of a travelling trunk, one end of which is open. In fig. 99, a muffle is represented. It is a clay trunk of from 10 to 15 inches in length, 5 to 7 inches in width and height. The size is determined according to circumstances. A small muffle of 10 by 5 inches is for small assays all-sufficient. In the two sides of the muffle, a series of round apertures is formed to cause a draught of fresh air to pass through the interior. The muffle is made of fire-clay, about half an inch thick and well backed before it is walled in. In large cities muffles may be bought ready made in potters' warehouses. The vapors and oxide of lead which are the result of the cupelling operation, are very severe on the clay of the muffle, and the bottom of it suffers more than any other part; for this reason, the bottom is covered sometimes with bone ashes or common ashes. This is however of little use, for the lead will still reach the clay. It also causes the cupel to heat slowly. When a bottom is eaten through, the muffle is of no further use and must be replaced by a new one. In fig. 100, a furnace is represented in which the muffle is walled in. We see in this instance that the whole of the muffle is surrounded by hot coal; it is in the centre of the heat; its bottom is about five inches above the grate-bars, so that coals which come down on both sides may fill the space below. The bottom of the muffle need not be so hot as the top. The oxidation and evaporation of lead is caused by reflection from the top of the muffle. One end of the muffle rests in the front brick wall, and the other is supported by a bracket of brick in

Fig. 99.

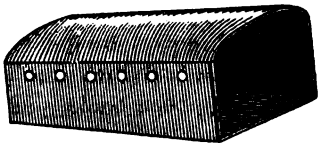
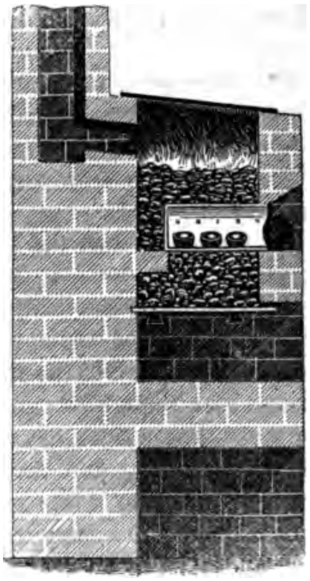


Fig. 100



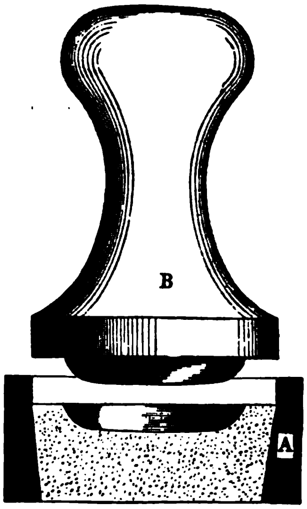
the opposite wall. The bottom must be perfectly horizontal in order to afford to the cupels a horizontal position. The operation in this furnace is simple and easily performed; we shall speak of this hereafter. The fire is kindled below the muffle, and in the first stages of the operation, some few pieces of charcoal are laid at the mouth of the muffle, in order to heat it quickly and uniformly. This furnace, with its muffle, is also used for roasting and calcining ore.

When a muffle cannot be obtained, a large crucible may be set in a furnace and serve the same purpose; or if no cupel furnace can be had, a cupellation may be performed in a crucible, in the bottom of which a hole has been pierced. The cupel is set on a level with its metal in the crucible, and the latter in the smelting furnace, so that air may be drawn in from below through its bottom, and pass around the cupel, the top being uncovered. It requires some attention to prevent the crucible from falling on one side, in consequence of the unequal consumption of fuel in the furnace. The pierced crucible may also be posted on a pierced sole-piece. This mode of working keeps the cupel rather cool. In a charcoal fire, a sole-piece is of great utility; in a coke fire, a little attention will be equivalent to the sole-piece, and in an anthracite fire there is no difficulty whatever in cupelling in this manner.

The instruments used in cupelling are a pair of small tongs, some hooks of iron wire, and at times bent glass rods, also a pair of light tongs and an iron spoon for bringing the lead upon the cupels; the latter is likewise frequently required to melt a little lead and pour it into the cupel. A piece of clear glass is used to protect the eye against the radiating heat from the muffle while examining the operation. All the tools should be provided with wooden handles, or they will become hot very soon, and burn the hands, causing accidents which may lead to the loss of the assay. The fuel is supplied to the furnace from above, by removing the plate of sheet-iron which covers the top.

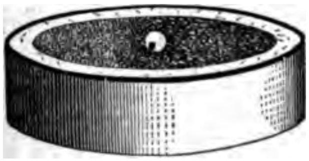
Cupel.—Those small flat crucibles in which a part of a metallic alloy is oxidized, and the oxide absorbed by the vessel, are commonly made of white bone-ashes. A variety of materials can be used for the same purpose, but none are superior to bone-ashes, and few cheaper and more readily obtained. A good cupel is a most important instrument in the dry assay. The quantity of precious metal contained in a ton of alloy is often determined by operating upon a few grains of the alloy; and if the cupel is imperfect, the result must be so likewise. For making cupels the bones of sheep, or oxen, or, in very particular cases, the cores of ox-horns, are used; these are broken fine and burned in an open fire of charcoal, and the white ashes resulting from the operation are ground fine and saved for occasional use. It is essential to good success in cupelling, that all carbonaceous matter should be expelled from the bones. The calcining is therefore repeated when any doubt exists as to its having been performed perfectly in the first operation. The bone-ashes must be perfectly white, without a shade of gray when moistened. The burned bones may be crushed in a mortar, or ground in a mill. In all cases they must be converted into a fine powder, which is worked through a fine silk sieve, and subsequently washed in lukewarm water. The latter operation removes the soluble salts which are in the ashes. It may be repeated to free the powder entirely from such salts, because these absorb always moisture, retain it, and cause the cupel to crack on being exposed to heat. The remaining powder consists chiefly of phosphate of lime, mixed with a little carbonate of lime, and some siliceous matter derived from the ashes of the charcoal. The cupels are formed in a circular mould made of bronze or wrought-iron, or of steel. This apparatus is represented in fig. 101 in section. The mould A forms a ring, more or less inclined within, nicely turned and smooth; this mould is firmly set on an iron plate, and filled with previously moistened bone-ashes. These are pressed into the mould by an iron ramrod until it is filled. The pestle B is then set upon the surface of the ashes, and driven firmly into it, forming a smooth concavity in the cupel. In driving the pestle with a wooden mallet into the mould, it must be turned around its axis, which will cause the cavity to become smooth. In order to facilitate the latter operation, a little dry bone-ashes is sifted upon the cavity, which causes its surface to be more compact and assume a perfect

Fig. 101.



smoothness. Small cupels, such as those of from ½ inch to two inches diameter, are strong enough when manufactured in this manner. Larger cupels, even those of two inches in diameter, are not strong enough to resist the influence of a great heat without breaking. When this happens, the assay is lost, or at least uncertain. Large cupels are made by filling an iron ring with bone-ashes, as is shown in fig. 102. Such a ring has the diameter of the cupel, and is from ¾ to one inch high. It is filled with damp ashes, firmly rammed in; and the cavity is scraped out by a knife, and polished by rubbing it smooth with a convex steel button. The iron ring, which may be roughly made, is used so long as it is not burned, and often serves for twenty and more successive cupels and smeltings. Each refining, or assay, requires in all cases a fresh cupel.

Fig. 102.



The moistening of the ashes for making the cupel is a delicate operation, particularly when they have been dry for some time. The degree of dampness at the time of making the cupel has a marked influence on the result of the operation. If the ashes are too damp the cupel will be porous, and liable to absorb metal with the oxides. If the ashes are too dry, the cupel will be close, not sufficiently porous, and work slow; it requires a high heat to imbibe the formed oxides. The best time for making the cupel is when the ashes have been washed with warm water and are thoroughly wet. In this damp state they are exposed to the influence of a warm room, or to the rays of the sun, and constantly stirred to prevent particles becoming too dry. The mass is dryed in this manner until it will hardly adhere together when squeezed between the fingers. It is now wrapped in paper and surrounded by a damp cloth, to prevent the evaporation of more moisture. In this state it is employed for making cupels at once. Some manufacturers use farinaceous substances, such as beer or dissolved starch, for glueing the ashes together. When this way of damping the ashes is adopted, the cupels must be exposed to a red heat before they are fit for cupellation. Such admixtures cause the cupels to be porous, and for alloys of gold, silver, and particularly copper, too porous. Good cupels consist of ashes neither too fine nor coarse; fine ashes are required for alloys of gold and silver. The cupels for pure gold or pure silver may be made of coarser ashes than those for alloys. In assays on minerals we hardly ever know if the refined metal is pure or alloyed; it is therefore necessary to make use of the finest kind of bone-ashes, and use more time in cupelling. Coarse ashes cause the cupels to be weak, and liable to break; and what is worse, such cupels imbibe the metal as well as the oxides. All the disadvantages resulting from the use of fine ashes are slow work, more fuel and time; but the assay is always more correct than in cupels made of coarse ashes.

Fluxes.—The additions made to ore in smelting it in the crucible are different in form, but not in kind, to those used in the large operation. Fluxes are used to make refractory matter fusible; convert earths into glasses and slags; separate earthy matter from the metallic oxides, and afford to these an opportunity of combining with the reducing agent. It is, therefore, a leading principle in all metallurgical operations, first to combine the foreign matter with a flux, and then reduce the oxide to metal. Fluxes are also used to prevent the formation of alloys; the flux is then of such kind as to prevent one or more of the metallic oxides from being reduced. Fluxes may be alkalies, acids, salts, metallic oxides, or metals. The most generally useful fluxes are lime, magnesia, clay, and silex; in addition there is glass, borax, fluor-spar, potash, soda, saltpetre, common salt, black flux, litharge, sulphate of lead; the oxides of copper, iron and others; metallic lead, iron, copper and bismuth.

Silex.—In some assays we need the addition of silex to the ore. We obtain it by heating pieces of pure crystalline quartz or pebbles to redness, and throwing them suddenly into cold water; a friable mass is obtained, which is easily converted into a fine powder in a mortar. In case the powder is colored by a metallic oxide, it must be boiled in muriatic acid to remove such oxide. It is not difficult to find pure quartz pebbles anywhere. Silex is that foreign matter most generally found in ores, with which we have to contend. It is never wanting in any metallic ore, and we must vitrify it to remove it. We shall for these reasons insert the most characteristic combinations of silex and other matter; the latter form the fluxes for silex.

Potash.—This forms a very fusible compound with silex. It increases the fusibility of any slag. Four parts of potash and one of silex fuse in a brown-red heat, forming a silicate which is soluble in hot water. One-twentieth part of potash to silex, forms a fusible slag in a white heat. In case the potash applied is a carbonate, the presence of carbon is required to consumate its combination with silex.

Soda acts similar to potash with silex, its combinations are to all appearances more fusible than those of potash. It is certain, that the same proportion of soda to silex, forms a more fusible and a stronger compound than potash.

Potash and Soda.—A mixture of these two alkalies forms an extremely good solvent for silex; equal parts of flux and silex are perfectly fluid in a cherry-red heat.

Baryta.—This does not form very fluid glasses. If the quantity of alkali is too large, the mass is infusible, and if silex predominates, the mixture cannot be melted. Two parts of baryta, and one of silex, and one of baryta and two of silex, are the extreme compositions of a fusible slag. Baryta is generally employed as a carbonate, and in the presence of carbon. Lime acts like baryta, so does magnesia.

Clay.—This does not melt readily with silex, yet in a high heat, one part of clay and three parts of silex may be converted into a stony vitreous mass; more clay causes the mass to be spongy and brittle, even after it has been exposed to a high heat.

Various mixtures of these alkalies, with silex, containing at the same time three or more elements, are more fusible than a mixture of a single alkali and silex. Where one alkali is present in a mineral, the addition of a second will increase its fusibility, and so will the addition of a third, fourth, &c., provided the alkalies do not so far preponderate as to make the slag refractory. As a general principle we may assert, that the multiplication of fluxes increases the fusibility of the slag. The addition of a fire-proof salt, such as a fluoride, chloride, &c, considerably increases the same effect: and if it is not desirable to add silicates for forming a slag, these salts will accomplish all that is required. A combination of clay and silex will bear a large quantity of lime, or other alkaline earth, before it ceases to be fusible.

Manganese, and the oxide of cerium, act in a similar manner in respect to silex. They form easily fusible slags. The extremes appear to consist of one part of protoxide of manganese and five parts of silex, and two parts of manganese and one of silex. These and all the abovementioned silicates may be formed in a crucible lined with charcoal. This is not the case with those which follow; and if we desire to form a slag of the metal which is present in the crucible, we must prevent the action of carbon on the slag.

Iron.—The oxides of iron form an extremely good flux for silex, particularly the protoxide; but they are reduced to metal in the presence of carbon. The extremes of fusibility are one part of silex and five parts of protoxide of iron, and one part of the latter to one and one half of the first. Peroxide of iron does not melt with silex.

Copper.—This metal does not form very fusible silicates; one part of oxide of copper and ¾ of silex are hardly fusible in the strongest heat; five parts of oxide of copper and one of silex compose the other extreme. Between these mixtures a fusible slag may be obtained, but it is always tough and pasty. Protoxide of copper forms slags of a more fusible nature than the oxide, particularly when clay is present.

Antimony.—The protoxide of this metal forms a silicate very readily, but it requires 3½ of the oxide to one of silex. It is doubtful if tin forms a silicate by itself; the oxide is soluble in silicates, but we do not know of its being a basis for silex. Zinc does not form a silicate; but if clay is present, oxide of zinc may be melted with silex.

Lead and Bismuth.—These act in a similar manner with silex; the oxides of these metals form very fusible slags with it. The extreme of lead appears to be, one part of oxide of lead and one and a half of silex. Less silex than this melts with the oxide of lead in all proportions. Bismuth causes silex to be still more fluid than it is rendered by lead. The oxide of lead affords a remarkable means of causing other silicates to be more fluid when mixed with them.

Silver, gold, chromium, and other metals, do not form distinct silicates, but the oxides of these metals are soluble in silicates.

Borax is here, as in a blow-pipe assay, the most important flux. It dissolves all the metallic oxides, silex, and all the alkalies, with great facility. The limits of its solvent power is in many instances extensive; but it is volatile in a high heat, and for this reason large quantities are often required to dissolve a mineral. All carbonates are dissolved under ebullition, caused by the liberation of carbonic acid; we are therefore compelled to use large crucibles in smelting with borax. This, when applied as borax-glass, is apt to boil with almost every substance with which it comes in contact when under the influence of heat. One part of borax and three parts of baryta form a fusible glass which is soluble in water. Borax has the same power of solution with lime, talc, and clay. A larger quantity of borax than that above-mentioned, dissolves these substances at a cherry-red heat. Heavy spar, fluor spar, the oxides of manganese, iron and lead, and sulphate of lead, dissolve readily in equal weights of borax; oxide of lead dissolves readily at the rate of seven to one.

Fluor-spar.—This is not often employed as flux, because it is not always found pure. It is, however, so good a solvent for many substances, that we cannot do without it. If silex is chiefly present when we employ it as a flux, a large quantity of fluorine is evaporated, which carries with it some of the silex. In the presence of alkalies, clay, and metallic oxides, the solvent capacity of fluor-spar is remarkably increased. A mixture of fluor-spar, borax, potash, and oxide of lead, is soft under the heat at which water boils. Equal parts of sulphate of lead and fluor-spar melt in a very low heat. Most other sulphates melt readily with the spar. One part of fluate will dissolve eleven parts of sulphate of lead, and form an exceedingly fluid glass; even one part of fluate will dissolve sixteen parts of sulphate. Fluor-spar also dissolves phosphates, but not perfectly; on sulphurets it has little influence.

Saltpetre.—This is easily decomposed in the presence of carbon, and then acts like caustic potash and soda. The presence of any mineral facilitates its decomposition.

Chloride of Sodium, common salt.—This forms a useful flux, but, as it is extremely volatile with some metals, its application is very limited. Salt facilitates the evaporation of metals; even copper, iron, silver, and gold, are subjects to be carried off by its vapors, when exposed to a high heat. At low heats it may be melted with hydrate of lime, and all the alkaline earths; it facilitates the solution of clay in other salts. With carbonates, sulphates and fluates, it forms very fusible slags. It aids the solution of metallic oxides, when present in small qaantities; but as all its combinations are volatile, it cannot be exposed to a protracted heat. In all cases, the salt may be extracted by water from the combinations it has formed under the heat, if it is present only in small quantities. It is most permanent when heated with alkaline earths or with clay. It has no affinity for borates, phosphates, and little for fluates; it does not combine with phosphurets and sulphurets.

Black Flux.—This forms at the same time a flux and a reducing agent; it is prepared by mixing two parts of cream of tartar, bi-tartrate of potassa or argol, with one part of saltpetre. The mixture is finely powdered, then put into an iron vessel and gently heated,—stirring it in the mean time with a red hot iron rod, or with a burning coal. The mass deflagrates gradually and forms a grayish black substance; this is pulverized, worked through a fine sieve, and then placed in a bottle with a glass stopper for use. This flux is a fine mixture of potash and carbon. It may be successfully imitated by dissolving molasses or sugar and potash together, heating and evaporating it in an iron vessel, and burning it in the same manner as the tartar and saltpetre, by stirring it with a red hot iron. A far superior flux is formed by a mixture of potash and soda in which sugar has been carbonized. In this operation the heat must be low in order to save as much carbon of the sugar as possible. A mixture of oil and alkali may be made to serve the purpose of black flux; also finely powdered charcoal and alkali. The latter mixture is not so efficient as the former ones, because the carbon is generally too coarse. Instead of sugar, starch may be used, but this is not equal in its effects to sugar. Soap is also employed in some cases where much carbon and little flux is required. In this instance the raw soap should be mixed with the test and evaporated in a large vessel, before exposing it in a crucible to the process of reduction, because it causes great ebullition, and wastes away the mineral in a small vessel.

Alkaline fluxes, to which the black flux particularly belongs, produce peculiar effects upon some metals; these combine with the metal of the alkali and form alloys, in case sufficient carbon is present for the purpose. This phenomenon is more or less observable in all metallurgical operations, and we shall allude to it in these particular cases. Antimony, bismuth and lead combine readily with potassium and sodium, and form an alloy in which these alkaline metals are found to the amount of two or more per cent. A heat of long duration, and the presence of finely divided carbon are most suitable to produce alloys of this kind. When carbon in a certain form is present, such alloys take place with great facility. In heating animal coal and potash together, the latter is easily reduced to metals, and if any other metallic oxides are present, these are still more quickly reduced than the potash. In manufacturing prussiate of potash, alloys of lead and potassium may be formed. Tin, antimony, and other fusible metals absorb a large quantity of soda or potassium, when their oxides are thrown ito the melted mass in the iron pot, wherein prussiate is melted, and stirred along with it for a short time.

Litharge.—This is a flux of great utility. It is used as a flux, and at the same time it forms, on being reduced, alloys with a number of metals by compelling them to separate from the ore. The common litharge of the shops, is not sufficiently pure for assays, neither is the carbonate of lead. The most certain method to obtain good litharge, is to heat the sugar of lead in a Hessian crucible, and evaporate the acetic acid, but it is not advisable to carry the process to melting. This operation may be performed in an iron vessel, in case a little iron is not regarded as deteriorating the assay. Litharge melts readily with most minerals; with alkalies and the alkaline earths it combines; the latter, however, are generally only suspended in its mass, forming a slag of a stony appearance. The presence of carbon separates metallic lead. All the silicates are easily fusible in litharge. Clay or aluminates are not so quickly dissolved as silex and silicates; five parts of litharge to one of clay is hardly softened by a strong heat. Heavy spar acts in a similar manner as clay; nor does gypsum form a more fusible slag with litharge than either of them. Similar to these is the action of fluor-spar and phosphate of lime. The oxides of titanium and manganese are not easy dissolved by litharge. It requires from five to six parts to form a fusible slag. Most of the oxides and salts of iron form a fusible compound with four parts of the oxide of lead. The oxide of copper does not require more than three parts of litharge to form a fluid slag, when exposed to a moderate heat. The oxides of antimony and lead melt in all proportions. Tin-oxide requires six parts, and also the oxide of zinc, to form a fusible mass. Arsenious acid melts with equal parts of the oxide of lead, forming a transparent yellow glass; the presence of silex does not interfere with the fluidity of the compounds. The oxide of lead forms an exceedingly good flux for silex, particularly when in combination with other bases. In all instances, one part of silex to four parts of litharge form a fusible slag. When clay, lime and other substances are present in the mineral under assay, it is advisable to add some borax to the test; this increases the solvent power of litharge.

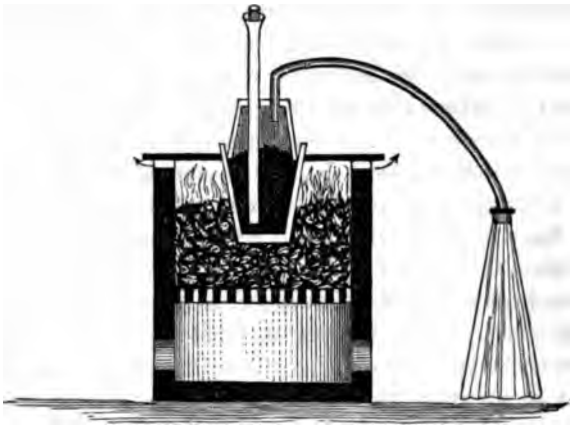
Sulphate of Lead.—This substance forms a comparatively good flux. It is decomposed in the presence of carbon or silex, or lime, and forms litharge, and will flux these substances. It forms also a flux for sulphurets and chlorides, superior to litharge.

The Oxide of Copper serves as a flux where any of the previcious metals are to be separated from their ores and combined with metallic copper. Oxide of iron, metallic iron, and silicates of iron are frequently used as fluxes, particularly where a refractory metal is to be reduced which will not melt unless another metal is present with which it may combine.

Reduction.—The means by which oxygen or the other elements are separated from substances in order to restore these to their metallic state, is termed the reducing agent. In assaying, most of the ores are oxidized already, or are artificially oxidized before the process of reduction is entered upon; in this case the means of reduction are hydrogen, carbon, fat oils, tallow, pitch, sugar, starch, gum, tartaric acid, oxalic acid, and in fact all those elements which absorb oxygen from the metals. When sulphurets are under treatment, metallic iron or lead is used to absorb the sulphur and liberate the metal.

Hydrogen.—When this gas is produced by dissolving iron or zinc in a diluted acid, it is always moist, and hardly suitable to perform a delicate operation. The hydrogen gas used in reducing metallic oxides should be dry; and if any foreign substances may be admitted to the metal it is carbon, which generally does the least harm to the operation. Carburetted hydrogen or coal-gas, is used to reduce oxides under a low heat; the carbon which is precipitated in the formation of the metal is removed by washing. Instead of the carburetted hydrogen from the gas works, the gas produced from oil or resin in a hot crucible is used to better advantage. If we fill a crucible with coarse charcoal powder, and lute on the top of it a second crucible inverted, and insert in the bottom of the covering crucible a tube, we may condense the gas into a receiver, such as a gasometer or an India-rubber bag, and preserve it for occasional use. Such an apparatus is represented in fig. 103. In this instance, the lower crucible is larger than the upper; the lute is made of clay moistened with a solution of common salt. The feeding-pipe, having a funnel at its top, which may be stoppered up by a cork, reaches into the charcoal, but hardly to the bottom of the crucible. The gas-pipe leads to a gasometer, or if arrangements are made to cool the gas before it leaves the pipe, it may be conducted into a caoutchouc bag. A cooling apparatus will be described under the title of Quicksilver. The gas produced in this manner is not quite pure, but is free from moisture. When the first portions of it are suffered to escape, the other admixtures of the gas are not injurious to an assay. The pipes must be made of iron; fine specimens of which may be obtained in any city at moderate prices. The temperature to produce the gas must be held as low as possible, in order not to carry over more carbon than is actually necessary to decompose the oil or resin. The feeding of the crucible is performed gradually, which prevents the generation of gas too rapidly, and consequently the fracture of the luting or the crucible. The plate by which the lower crucible is sustained may be either of cast-iron or sheet-iron, or a stone slab.

Fig. 108.



Hydrogen, or carburetted hydrogen, is applied by leading it into a glass tube, which contains the ore specimen in a proper form already heated; a gentle current of the gas is passed over the ore until no more is burned by it, which is manifested by its escaping in a pure state.

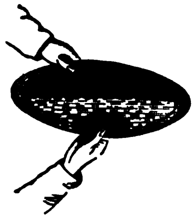
Carbon.—Refractory metals may be reduced by means of hydrogen, but as the temperature required to melt them is generally high, carbon is used for reduction with more certainty of success. The affinity of carbon for oxygen is not very strong at low temperatures, but at a red-heat it surpasses that of most other substances. It removes therefore, the oxygen from most combinations. The temperature at which the various kinds of coal combine with oxygen is variable, and in assays we must be mindful of this peculiarity of carbon. Charcoal produced from soft wood, such as willow and pine, is exceedingly combustible. This feature is augmented by charring the coal in the lowest possible heat. The light coal of which gunpowder is manufactured, is far more combustible than that formed of hard wood in a heap in the open air. Charcoal used in assaying is selected according to the quality of the ore to be assayed; in most cases the coal is finely pulverized, in others it is used in grains. If perfectly pure coal is required, free from all gas, moisture and hydrogen, it is pulverized and exposed to a red calcining heat in a crucible; such coal requires a higher heat for combustion. The ashes contained in charcoal have no marked influence on the result of an assay, when the operation is performed with the usual care. If pure coal is required, such as is free from all ashes, we may obtain it by calcining crystallized sugar. Carbon is much inclined to form combinations with most of the metals, but not with the slags; any excess of it in an assay, therefore, causes delay and often a failure. In such a case the fine coal hinders the slag as well as the metal from running together; and we find the assay in the form of a porous mass, consisting of grains of metal and agglutinated cinder, mixed with carbon. When an excess of carbon may injure the assay, we melt the test in a crucible lined with carbon. Oil, tallow, and resin, are also used instead, or mixed with charcoal. This is done when the metal produced cannot bear a high heat. The use of these volatile substances requires extreme caution to succeed well. Of other reducing agents, we shall speak under the title of those articles to which they are applied.

Power of Reduction—The capacity of carbon, or carbonized material, is determined by mixing pure litharge with it, or its compounds finely powdered, and weighing the resulting metal. Pure carbon, when mixed intimately with an excess of the oxide of lead, should produce 34·31 parts of metal for one part of carbon. By experiment it is found that one part of pure charcoal produced 31·8 parts of lead; common charcoal, 28; oil or fat, 17·4; rosin, 14·5; sugar, 14·5; starch, 11·50; gum, 11; tartaric acid, 6, and oxalic acid only ·9. This capacity relates only to lead and those metals which are reduced and melted at the same degree of heat: to iron or copper these numbers cannot be applied.

Smelting.—In the assay by fusion the object is to produce a metal in its pure form, directly from the ore, and in some instances to produce all the metal of a certain kind which the ore may contain, with a view of comparing the result of the assay with the smelting process on the large scale. To succeed we must deoxidize the ore, and produce at the same time so much heat as to melt the metal; in addition, the foreign matter in the ore must be converted into a fusible scoria, which generally floats as a light glass on the top. Different ores require different modes of operation to produce the metal. Often a variety of the same ore must be subjected to different processes. For the latter reason we convert most ores, which are to be examined, into oxides by roasting. When a specimen is to be assayed we ought to know, at least approximately, its composition, in order to modify the manipulation accordingly. In most instances, we recognize the quality by the appearance of the ore; in others, we apply the blowpipe as an introductory examination. We shall, in order to facilitate the operation, describe the most prominent marks of the ores which may come under examination, and the class to which they belong. If an assay is ineffectual at first, it is repeated with proper modifications until a satisfactory result is obtained. There is not much difficulty in this, as it chiefly requires the production of a suitable slag.

Gold.—An assay of gold ore is not difficult. If we expect gold in a specimen, we pulverize it finely; then pass it through a fine sieve, and wash the powder in an iron pan, or a blackened pan of any kind of material. Fig. 104 represents the manner in which the operation is performed. A pan is held in one hand firmly, and some water poured upon the ore; the other hand is now used for shaking the pan in a gentle but rapid manner. The powdered ore being thus gathered to one side, the heavy grains of gold descend through the sand to the bottom of the pan and settle in the corner. After shaking the pan a few minutes, it is to be moved so as to produce a gentle current in casting off the water. This will carry with it some of the sand, and diminish the quantity in the pan. In repeating this process with fresh water, another portion of sand is removed from the sample; and if the shaking and removal of sand is continued, the latter may be washed off entirely,

FIG. 104.



or nearly so. The principle involved is, that the debris of rock is lighter than the gold; the latter will therefore sink to the bottom, and the former pass off, by moving the water gently on the surface of the pulverized ore, which is always retained in the same place, in a corner of the pan. When the sand is thus nearly washed away, a little water is retained in the pan, moved around by inclining the pan, so that the water flows always into its corner or lowest part. This gentle current will move the debris of rock to another part of the pan and expose the metal to view. When this operation is performed on crushed rock, or on alluvial soil, it is in all cases necessary to pulverize the mineral that no particle of metal may escape detection. In this manner we cannot make a quantitative assay; for, with the greatest attention, we lose half of the metal. Gold is very fine when its ore has been crushed, and it is carried away by the water in washing off the rocky matter. In most cases we detect the gold in its metallic state. When an ore is thus treated, and we do not find it in the residue—which may happen in silver ores, in the tellurets, and sulphurets, and arseniurets—we crush the ore, as before, mix it with the fluxes and smelt it.

Gold ores are not often so rich in metal that a small quantity smelted would furnish a safe estimate of the average contents of a mine. It is, therefore, necessary to assay at least 500 or 1000 grains at once, and repeat this operation on various parts of the vein. If the ore is a ferruginous slate, or quartz, it is intimately mixed with half its weight of pure litharge, half its weight of borax-glass, and one part of carbonate of potash; these ingredients must be well dried and the whole then finely pulverized. This mixture receives an addition of sufficient carbon to precipitate a certain quantity of lead in the metallic state; and as one part of charcoal produces 30 parts of metal, we add accordingly. From 1000 grains of ore, 100 grains of lead may be produced, which will contain all the gold present; and in order to obtain these, we add 4 grains of fine charcoal and mix it intimately with the ore and flux. Here is more carbon than is required, but we must consider that a little carbon is always lost in the operation. This mixture is put into a Hessian crucible, which should not be more than half filled; for the mass, when heated, will boil and overflow the brim of the pot. Instead of carbon, black flux might be used; but as we do not know the amount of carbon in that flux exactly, we are exposed, in using it, to the producing of too much or too little lead. Over the test in the crucible a little common salt, a stratum of about a quarter or half of an inch thick, is laid, which will prevent the evaparation of carbon and accelerate the solution of metallic substances in the ore. The use of a graphite, or blacklead crucible, is inadmissible in this case; for its carbon would precipitate more lead than is needed, and cause it to be impure. The crucible and contents are now placed in the furnace, covered by a slab to prevent the falling in of coal, and surrounded with coal so as to cover the crucible; fire is then applied at the top by adding hot charcoal. The fire thus kindled will heat the crucible from the top downwards, which protects the pot and prevents its fracture. In half an hour the fire should be drawn to the grate-bars, and fresh coal added, sufficient for at least three quarters of an hour; the furnace is then covered, the grate cleaned, and a vigorous heat applied. In half an hour the furnace-cover is partly removed, the cover of the crucible lifted, and the contents examined. If the mass is fluid but still boiling, that is, throwing up gas-bubbles, the pot is covered again; and when there is a deficiency of coal to last the heat out, a fresh supply is added to complete the assay. When coke, or anthracite is used, we need not add fresh fuel to a once charged furnace; the use of charcoal, however, makes this invariably necessary. As the addition of fresh fuel delays the operation, and is in some cases injurious to the assay, we see the importance of using hard coal, either coke or anthracite, in crucible smeltings. A strong heat, and one of short duration, is all-important in this assay; for lead is volatile, and the flux will at last eat through the crucible.

After the lapse of about ten minutes, the contents of the crucible are again examined; and if the mass is now found to be perfectly fluid and quiet on its surface, the covers of the furnace and pot are removed, the fuel rammed down by means of an iron rod, and the crucible withdrawn from the fire and set in a dry or warm place on the brick floor. The crucible may be withdrawn by a pair of blacksmith's tongs, the fire-lips of which are nearly as long as the shanks, thus causing very little pressure upon the sides of the pot. Basket tongs may also be used, similar to those of the brass-founders; but they are generally too heavy and clumsy for assaying operations. On putting the crucible down on the floor some few gentle taps are given to it, to gather in the bottom those globules of metal which are suspended in the slag.

When the crucible is perfectly cool, it is broken over a basin with water, that its contents may be examined when wet. In the bottom of the pot, a button of lead is found; and on breaking the scoria, we may examine it for grains of metal. If no metal is visible with the aid of a lens, all the parts of the pot and the slags are thrown away; if metal is visible, the pot and slag is to be pulverized, and washed, so as to recover it. This operation is performed in a wash-pan, like that with the crude ore above described. All the metal must be freed from adhering slags by means of the hammer and water; it is then weighed and a cupel selected of equal weight, or heavier, for refining it. In the subsequent article on "Silver," we shall describe the operation of cupelling, which applies here as well as to silver.

Use of Salt.—In this assay we recommend the use of salt in the form above mentioned, and not mixed with the ore and other fluxes. Salt is not a good flux, because it does not aid in the solution of silex directly; it merely dissolves the metallic oxides and prepares them to combine with silex. Most of the metals combined with chlorine are very volatile, and in assays, other than those of the precious metals, salt is inadmissible. Saltpetre is preferable to salt; but as the oxygen of the saltpetre is soon absorbed by the carbon present in the mixture, no lead will be precipitated; or else all the saltpetre will be converted into alkaline flux, which is not a proper flux for gold or silver ores; it causes the lead to be so impure as to cupel with difficulty. Some common salt, or fluor-spar, is requisite to free the lead from iron, copper, and such metals, which delay and often spoil the cupelling of it. In these assays it must be the aim of the assayer to obtain pure lead in the first smelting; if it is not obtained, it must be remelted with a little saltpetre, or a mixture of saltpetre and common salt.

Sulphurets and Tellurets.—When gold ores are not perfectly oxidized, which frequently happens; when pyrites are present, or the gold is combined with tellurium or galena, the operation is somewhat difficult, if we expect a correct quantitative assay. In this case, as well as in the foregoing, we may assay by means of litharge, using four or five parts to one part of ore, or in fact, any quantity more or less than that specified, and precipitate as much lead as we want by means of a specified quantity of coal or black flux. Such an assay is never correct; the slag is decidedly alkaline, and it retains a portion of the precious metal which may amount to 10, or 20, or even a greater per centage of that contained in the specimen. In all cases, when precious metals are to be assayed, and the object is to obtain the whole amount, the slag which is formed ought to be of an acid nature; if not acid, it should be, at least, a neutral salt. Gold is soluble in an alkaline slag, particularly in an alkaline sulphuret; and it cannot be expected to follow the metallic lead when so dissolved, or suspended in the slag. The means commonly employed for the purpose have proved insufficient, and the author has been induced to perform a series of experiments which resulted in a more perfect mode of assay, and in a smelting operation, the benefits of which he has secured to himself by a patent right. This operation is as follows. When the ore contains sufficient galena, no lead is added; but when it does not contain lead, in some form or other, some finely-powdered litharge is added to the pulverized ore, and the whole intimately mixed. From ten to fifteen per cent. of oxide of lead is in all cases sufficient to procure all the gold. The pounded ore and litharge is mixed with about one half of its weight of common salt; the whole mass is moistened with water so as to dissolve the salt, and then exposed to evaporation under constant stirring. When dry, the contents are gently heated in an iron pot with a concave bottom, and as soon as any signs of melting are perceptible, the mass is diligently stirred by a bent iron rod. It soon becomes semi-fluid, and the heat should be modified so as not to make the slag perfectly fluid and evaporate the chlorine, for the latter must be retained. When the slag has been well stirred for a short time, a few small pieces of burning charcoal are added, and stirred with the cinder. The charcoal reduces the oxide of lead, and the heat must be so regulated that no lead can sink to the bottom of the pot, but is suspended in the semi-fluid slag. By constant stirring, the particles of metallic lead absorb the particles of gold which may be suspended or dissolved in the semi-fluid sulphuret, and an alloy is obtained, disseminated in small globules through the mass. About half an hour is sufficient time to finish this smelting operation; the iron pot is removed from the fire, and the mass quickly thrown into cold water. Then the slag dissolves, the salt is extracted, and there remains in the vessel a black, fine powder, which feels like plumbago; it consists of the sulphurets of various metals, and metallic lead in small grains and spangles. The sulphurets are extremely fine, and are held in suspension in the strong brine; fresh water should be added at discretion, the sulphurets gently washed away, and the remaining lead gathered for cupellation.

By this mode of assaying all the gold is easily obtained, but it requires a low heat and diligent work to make the operation successful. If sufficient iron pyrites is present, the addition of a little lead serves to secure the precious metal; if there is only a little iron in the ore, a small quantity of oxide of iron should be added to decompose the sulphurets. A gentle heat, the presence of salt, and the stirring, cause the evaporation of some sulphur, also arsenic and tellurium, and the sulphurets are thus deprived of the power to dissolve gold. The gold is now suspended in the pasty mass, and obtained by combining it with metallic lead. If the combination is produced when the mass is in a state of rest, many particles of gold may be lost, because they are fine, and washed away with the water and the fine sulphurets; diligence is therefore necessary to make the operation succeed well. The presence of any alkali will injure this operation, and if some of the lead remains in the form of a sulphuret in the slags, the assay is doubtful. There is no danger of reducing the ores of iron, copper, or other metals by carbon; gold, silver, the platinum metals and lead are the only ones which can be obtained. The addition of an excess of carbon under the influence of a limited heat, has therefore no other effect than to increase the mass and the labor in washing. The lead obtained in this operation may be re-melted in a crucible along with a little saltpetre to form it into a button and to free it from impurities.

In ancient times, assayers melted pyrites in potash and soda, and dissolved the slag in warm water, supposing that all the gold was contained in the alkaline sulphureted solution. But this was a mistake; gold is soluble only in alkalies which contain a large quantity of sulphur. Sulphur must, therefore, either be added to such an assay, or the gold will adhere to the metallic sulphurets and be precipitated with them. It is very doubtful if with the addition of sulphur the whole amount of gold is obtained in the solution, because it is not very soluble in that menstruum. Other metallurgists recommend to melt the pyrites with saltpetre and litharge, then to evaporate all the sulphur and produce metallic lead. This is a safe way of assaying, but as saltpetre is easily decomposed and forms an alkaline slag, it requires either a very large quantity of the flux or the assay is incorrect. It needs at least an amount of saltpetre equal to that of the ore when clean, and if the slag is not very liquid, a part of the gold will remain in it. The method of roasting or oxidizing the pyrites, and removing the oxide by washing, is so imperfect that it deserves no further notice.

If gold is contained in metals, such as refuse iron, tin, zinc, brass, or copper, under the form of works of art, it is scraped off with a scraper or file. This labor may be accelerated by oxidizing the metals at a low heat. The gold thus obtained, as well as jewellers' sweepings, are either melted with saltpetre, or with saltpetre and lead; in the latter case, some lead is obtained which contains all the gold, and may be cupelled in the usual manner. In this case tin or zinc is frequently present in the refuse, and as the oxides of these metals do not melt in saltpetre, it is advisable to add some common salt to the assay, to remove them from the lead, for these render the operation of cupelling slow and tedious; and if zinc or antimony is present, some of the gold is carried off by the evaporation of these metals. If sufficient saltpetre is used, and a little common salt, there will not be any other metals than lead and gold or silver in the button. It has been proposed to free gold from other metals by means of sulphuret of antimony, but this operation, which is generally practised by jewellers for refining their gold, is not applicable to an assay, because it is never correct. We shall refer to this subject in the third part of this work. It has been also proposed to oxidize artificially all the metals which may be combined with gold, by using black manganese or oxide of iron. This method is not sufficiently correct to deserve any notice; for in all instances the oxides which are formed contain gold in small particles which never can be recovered.

The true principle of an assay for gold, in all cases, is to form a very fusible slag which absorbs all the metals; and as the gold will adhere readily to melted lead, it should be brought in contact with that metal in a state of fusion, and all the particles will be obtained. Common salt, or borax, remarkably promotes the solubility of metallic oxides, and in fact dissolves them very readily. In all cases, therefore, where we have to deal with metals or metallic oxides, either one or the other should be present; but, as borax causes other metals than lead to be formed, and salt produces only the precious metals and a limited quantity of lead, the presence of the latter is, in all cases, preferable to borax, when the precious metals are the object of the assay. There is no substance which dissolves metals more readily and converts them into oxides than chlorine, and when this is present in a sufficient quantity, the precious metals are not excepted; but when metallic lead is once produced in a crucible, it is only necessary to bring the dissolved gold in contact with the lead and it is absorbed by it.

Metals and Gold.—When other metals are alloyed with gold, we separate the first either by cupellation, or if the kind and quantity is not suitable, we convert the first into oxide and divide the latter. The alloy of lead and gold is the most suitable for cupellation, and it is in all cases advisable to remove all other metals and convert the alloys into this combination. As gold is very volatile, these conversions must be performed by as low a degree of heat as possible. The cupellation of lead and gold is perfectly safe and easy: this is not the case with other metals and gold. Copper and gold combine very readily, and in fact more so than lead and gold, but this alloy cannot be cupelled; it is therefore melted with lead, and the latter causes the oxide of copper to be absorbed by the cupel. The operation is uncertain, for the oxide of copper will absorb gold and carry it off. Such an assay is never correct, the refined gold containing copper, and the oxide of copper, gold. The same is the case with all other metals, and it is an object of peculiar importance not to cupel a test wherein other metals or substances than lead are contained. Other alloys than those of lead should be dissolved in muriatic acid, and precipitated by carbonate of soda, and the precipitate smelted like a mineral. In smelting, an excess of litharge is used; the quantity of lead is determined by the carbon which is added. An alloy of copper and gold requires a large quantity of lead for cupellation. We may assume that 100 parts of lead to one of copper is not too much, considering their relation, and the uncertainty of success in such an assay. It is easily understood that the solution of the alloy, and its precipitation with an alkali, is the only safe way of proceeding. As an alloy of gold always contains some silver, and as gold is not soluble in muriatic acid, the remaining parts which do not dissolve in the acid must be smelted with the precipitate. There would be no necessity of precipitating the solution, and merely smelting the residue would answer the purpose, but for the circumstance that chloride of silver is soluble to a certain extent in other or soluble chlorides; and, as in most cases the amount of foreign metals is small, this method does not increase the labors of the assayer.

If the quantity of a metal in a test specimen is large, it is advisable to make a sulphuret of the alloy. This is accomplished in melting the specimen by adding gradually sulphuret of iron, coarsely pounded; the native pyrites contain sufficient to produce this effect on a large quantity of other metals. Galena may be used also, but it is not so effectual as iron pyrites. If neither iron nor lead pyrites can be obtained, pure sulphur is used, which is added to the melted or heated metal in small quantities and in the form of a coarse powder. The resulting sulphuret is then treated as native sulphurets, as has been stated in former pages.

Platinum, Silver, and Gold.—The presence of the first of these metals causes the cupellation to work slowly, and in some cases, particularly when copper is present, the gold does not form a globule at all, but is carried with the oxide of copper and the platinum metal over the cupel. In such cases we melt the test with some silver, of which at least twice the amount of the gold alloy must be added, and also some lead to make the mass fusible; it is then cupelled in a strong heat to obtain the metal in a perfect globule. The quantity of lead is variable; if the heat in the cupel is strong, which is the most advantageous, the quantity of lead may be 12 or 14 times that of the alloy. If the heat is low, but sufficient to melt the alloy, the quantity of lead must be at least 20 times that of the alloy. In all cases the resulting refined metal is adulterated by copper if that metal is present, which is more likely to be the case if the heat has been low in the cupellation. If no copper is present, less lead may be used in refining the metal. The presence of platinum in a test is recognized by the globule, which assumes a flattened instead of a round form—this is pre-eminently marked in pure gold; silver, or an alloy with much silver, is also liable to form a flat globule in the shape of a hemisphere, while that of platinum is distinctly flattened. One per cent of platinum will cause the globule to be rough and rugged on the surface, while pure gold and silver is perfectly smooth and shows a mirror-like lustre. In all cases the presence of platinum causes the globule to be dull and lustreless, often showing crystals on the surface. When the alloy contains more than ten per cent. of platinum, the cupel is covered with a silver coating, under the influence of a strong heat, which is often yellowish or grayish, and consists of platinum metal.

Moist analysis.—When a globule of gold is obtained in the process of cupellation, it is never pure, particularly when derived from a mineral. The globule, for the purpose of testing it, is flattened on a steel anvil with a hammer; at first it is placed directly on the naked steel, and afterwards between strong and thin paper. It is next exposed to the influence of pure nitric acid, which must be free from muriatic acid, which will not cause a precipitate with nitrate of silver. If the gold is nearly pure it is not attacked by the acid; we melt it then with some pure lead, about equal to twice its weight, and dissolve this alloy. The nitric acid, gently heated, will now hold in solution the lead and silver, and leave gold, platinum, and the platinum metals at the bottom of the vessel. If pure silver is at hand it may be melted with the globule, of which an equal weight is sufficient. The result is more certain than by alloying it with lead. The residue of the solution is treated with aqua regia, which dissolves the metal. The solution thus obtained is evaporated in a flat porcelain dish, over a basin of boiling water, which causes the evaporation of all the acid. The dried chloride of gold is now dissolved in water, and to this is added a fresh solution of proto-sulphate of iron, which in a short time precipitates the gold in the form of a yellowish brown powder. This is dull and lustreless, but assumes brightness when filtrated, dried, and burnished by a hard and polished substance. The proto-sulphate of iron is prepared by dissolving copperas, and adding to the solution pure metallic iron. This solution must be prepared some days previous to its use, for the iron does not dissolve very readily in the copperas. A surplus of metallic iron should always be in the solution. It is advisable to use both gold and iron solutions in a somewhat diluted state; it does not then form a precipitate at once, but requires some time. The mixed solution appears at first to be light blue, and in reflected light reddish yellow; the gold gradually subsides in the form of a yellow powder. This powder is pure gold; it is filtrated on clean paper, and may be weighed in this state, or it may be gathered into a globule with some borax and saltpetre in a crucible.

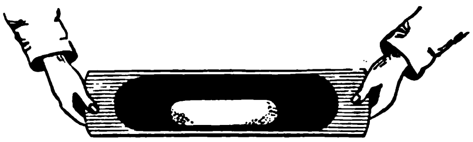
Remarks.—In all the assays of gold, we must be extremely cautious to avoid the presence of an alkaline slag; for in most cases some oxide or sulphuret of gold is always present in a mineral which contains gold. Both are soluble in alkalies, and if the slag we melt with is alkaline, we are uncertain of the results of the assay. Borax, potash, and soda are to be avoided, if possible; and the use of salt requires caution, for all these fluxes dissolve gold. Saltpetre is the most suitable flux, but in the presence of sulphur, carbon, and some of the metals, it is decomposed and ceases to be good. Chlorides are the most practicable fluxes; but as these cannot bear a high heat, nor one of long duration, the operation must be so arranged as to perform the assay in the shortest time which is possible. For these reasons the fluxes and mineral are mixed in a wet condition, to bring the particles in close contact before heat is applied—this facilitates the smelting considerably. The moistened mass must be dried before it is packed into an earthen crucible, because it will break the crucible when it is deposited in a moist state. Gold is not often found in large quantities in minerals; and as a minute quantity is sufficient to pay for its extraction, the assay of gold ore claims an attention which is not required in assaying the ores of other metals. Chlorides dissolve the oxide of gold, but not metallic gold; and when fluid lead is brought in contact with the dissolved oxide or sulphuret, it will absorb them; but as lead is heavy, it is inclined to subside, and thus deprives the particles of gold which still may be present in the slag, of an opportunity to combine with it; for these reasons we prefer the assay in an iron pot, with a constant stirring of the mass. The melted lead performs here the office of mercury in an amalgamation.

Platinum and Platinum Metals; Palladium, Rhodium, Iridium, Osmium. The latter metals are generally alloyed with platinum. Platinum is exceedingly refractory; it can be melted only when alloyed with another metal. When a grain of metal of a leaden appearance resists all degrees of heat, and neither melts nor oxidizes, we may conclude that it is platinum. If the grains of the metal are fine, and imbedded in rocky matter, it is treated as gold ore, melted with suitable fluxes, and cupelled. In this case silver must be present to cause the platinum to be fusible in the cupel. If no silver is in the ore, an addition of pure metal must be made to the assay. In a strong heat, platinum combined with two parts of silver may be cupelled. But as a strong heat is not generally at the command of the assayer, it is advisable to make use of more than two parts of silver to one of platinum. In most cases it is the best plan to arrange the assay so that one part of platinum in the ore is melted with 6 parts of silver and 50 parts of lead. If less lead and silver is in the alloy, the metals palladium and rhodium do not remain in the globule, but are spread over the cupel. If the amount of platinum in the test is not more than five per cent., or $\frac{1}{20}$ of the silver, the appearance of the globule in the heat of the cupel is similar to that of pure silver. If $\frac{1}{10}$ of platinum is in the silver, the globule does not show the bright glistening surface of silver or gold, but is dull and gray. With $\frac{1}{4}$ of platinum it requires a strong heat, and the cupelling is extremely slow; the grain is flattened, dull, and obstinately retains the last portions of lead. The globule thus obtained in cupelling, contains silver and platinum, and it may also contain gold and other metals; if thrown into concentrated boiling sulphuric acid, all the silver is dissolved, but not the platinum. The residue is platinum, and if gold has been in the alloy, it contains gold. It is then dissolved in aqua regia, some ammonia is added, and the solution evaporated over boiling water. The dry residue is triturated with alcohol of ·84 specific gravity, and dissolved in water after the alcohol has extracted the yellow liquid. The gold only is dissolved; the platinum remains as a platinum choride combined with chloride of ammonia. This is calcined in a red heat over the spirit-lamp, and the remaining powder, which is platinum, weighed. The gold may be obtained by means of proto-sulphate of iron. Too much silver in the alloy is not good for solution, because some little platinum appears to be soluble in sulphuric acid, when the amount of silver is more than 2 to 1 of platinum; but as this loss is very small, the assay indicates too little metal. When iridium is present the precipitate of platinum-ammonium chloride is reddish or brick-red, instead of yellow. The precipitate is then calcined in a porcelain crucible and dissolved in aquafortis, which alone dissolves platinum; this, when precipitated by ammonia, forms a yellow precipitate. The separation of the other platinum metals from the solution, is, if not difficult, at least of such a nature as to belong more to chemistry than to metallurgy.

Silver.—The assay of silver ore is, in itself, extremely simple. Most of the silver ores contain lead, others copper, which metals in many instances so far predominate as to make their extraction profitable. We make the assay in this case with a view to procure the accompanying metal. In all cases it is necessary to combine the silver with some lead in smelting, and separate the silver by cupellation. If there is not sufficient lead in the ore, litharge must be added to increase it. The test can be melted with metallic lead, also, in case litharge cannot be obtained sufficiently pure. Metallic lead should be pure. It may be tried by cupelling a part of that which is designed to form the matrix for the silver. If it proves to be pure in the cupel—that is, shows no other colors, but converts that of the cupel into a uniform whitish-yellow and no metallic globule remains, we may conclude the metal to be sufficiently pure for the purpose. The assays with metallic lead, and those with the oxide of lead, have their peculiar advantages: the first is for quantitative assays in the smelt-works; the second is the most convenient for qualitative assays.

Assay by Metallic Lead.—We thus assay all the ores in which we expect to find silver, or other precious metals. The lead used in this assay, the purity of which has been tested, is granulated in the following manner. The metal is melted in a clean iron ladle, the dross or sullage on its surface is removed, and the liquid poured into a wooden trough, which is previously rubbed over with reddle, in order to prevent the burning of the wood. The trough is represented in fig. 105. It is taken up with both hands and the lead kept constantly in motion until it is near congelation; at this point the lead is thrown up, and in falling back into the trough again it is broken into small fragments, which are often very minute, and the mass appears in the form of fine sand if the operation has been well performed. When all the lead is thus divided, and cold, it is thrown on a sieve, of about twenty meshes to the inch; the fine part is removed for use, and the coarse grains which remain are reserved for remelting. This lead, in quantities of two ounces for one test, is placed upon a flat dish, and mixed with the ore for smelting. The dishes used for this purpose are manufactured of good fireclay, similar to that of which crucibles or firebricks are made; a mixture of three parts of pure clay and four parts of refractory sand is considered a good composition. Dishes of three inches diameter are made by hand

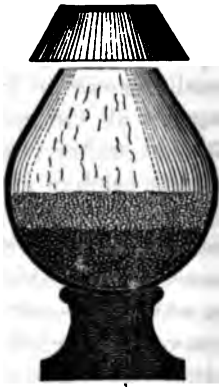
FIG. 105.



of this silicious clay, but where many are required, it is necessary to manufacture them by such a machine as is used for making cupels. The capacity of the dish must be abundantly sufficient to melt four ounces of lead and half an ounce of ore. These dishes, when first made, are too soft and porous for use; they are dried in the air and then baked in a furnace. Any potter can manufacture and bake them with his ordinary ware. With a cupel furnace, having a large muffle, a number of tests may be assayed at once; and in all cases, two tests should be assayed from every species of ore. Whenever meltings, smelting and cupelling are done at the same time, the dishes, pots, or cupels, are marked with reddle, and numbered in such a manner that each test may be recognized; this reddle mark is not obliterated by fire. Two ounces of granulated lead are laid around the edge of the dish, so that the concavity in the centre is free. In the middle, ⅛ of an ounce, or 60 grains, of ore finely pulverized, is placed, and some of the granulated lead mixed with it, in such a manner that the ore does not reach to the edge of the dish. The dishes thus prepared with ore and lead are pushed slowly into the heated muffle of the furnace; the most refractory specimens foremost, and those afterwards which melt easily. The ores which contain much silicious matter or iron, are refractory; those which contain pyrites chiefly, are very fusible. In a short time, say five or eight minutes after exposure to the heat of the muffle, the ore begins to roast, that is, exhale sulphur, arsenic, and other volatile substances, and the lead begins to melt. When ore and metal are thus heating, the mouth of the muffle is shut by a piece of hard charcoal, and the dishes gradually exposed to a stronger heat by stirring the fire; this must not be done too fast, because some ores foam in melting and flow over the lead, thus spoiling the assay. The principal object of this operation is to form a slag of the ore, and bring at the same time melted lead in contact with it in its molten state, which may absorb the precious metal. In case the ore does not contain sufficient flux for melting, some of the lead is oxidized by the heat, and forms a flux for it. It is therefore evident that too much heat is disadvantageous to the ore, because some of it may boil over the edge of the vessel and is lost. The heat must not be too slow to act, because in that case the oxide of lead, which is generated abundantly, will eat through the dish. The heat in the muffle is easily regulated, by putting more or less coal at the mouth. It is, therefore, advisable to have the fire rather too strong than too weak. After the lapse of fifteen or twenty minutes, we observe a bright metallic spot in the middle of the dish. It is the melted lead surrounded by the fluid ore, which is now in the form of a slag. The lead is all the time burning and evaporating; and if these vapors of it draw over the dishes, it is an indication that the heat is too low; on the other hand, if these vapors rise high on the roof of the muffle, the fire is too hot. The vapors of lead ought to form a cloud, which is suspended half-way between the roof and the bottom of the muffle. The withdrawal of coal at the mouth of the muffle will cool it, and the addition of coal heat it. When the bright spot in the middle of the dish disappears, the mouth of the muffle should be entirely shut, and a strong heat applied about ten minutes longer. This is the finishing heat; the ore becomes now perfectly fluid, and separates entirely from the button of lead below it. This heat is sufficient to finish the operation. The time consumed in the assay is between one hour and one and a quarter. The dish is now withdrawn from the hot muffle, and its contents cast into a previously heated iron mould, which has been rubbed over with some fat or tallow. After the contents of the mould are cooled sufficiently to adhere together, they are put into cold water, and the slag carefully separated from the lead by striking it with a hammer. This lead is ready for refining, and may be placed in the cupel. In case the ores contain very refractory matter, such as particles of clay, slate, heavy spar and quartz, about ten grains of borax-glass may be mixed with the ore; but if the test will work without, it is better. If a series of tests are to be assayed, it is the best plan to melt the whole of them before refining the lead.

Smelting with Oxide of Lead.—All ores may be smelted with the oxide of lead instead of metallic lead, which is preferable when much lead is in the ore. Some ores must be roasted before melting; these do not often present themselves, and generally we may smelt without previous roasting. The ore under examination is finely pounded, and mixed with double its weight of a mixture consisting of one part of saltpetre and two parts of crude cream of tartar. This is the composition of black flux, which may be used here to advantage in its crude form, particularly when sulphur is in the ore. The use of this mixture presupposes the presence of lead in the ore, and one ounce is smelted at a time; this brings the quantity of ore assayed to near five hundred grains. If no lead is in the ore, or very little, an equal weight of pure litharge is mixed with it, and the other proportions are the same as mentioned before. In most cases it is the best plan to take 100 grains of this kind of ore, and mix with the required flux for smelting. If we want a correct assay of lead, the test is not smelted in an earthen or clay crucible, but in a copper pot, so that all silicious matter is excluded. In fig. 106, a pot of this kind is represented. It is about ¼ of an inch thick in metal, and as the flux is exceedingly alkaline, very little lead can remain in an oxidized state in the slag. Over the mixture of ore and flux a stratum of salt is laid. This is necessary to prevent the flying of the ore. The crude flux, in detonating with the saltpetre, would throw out the ore unless it was covered with salt, especially if the narrow mouth of the copper pot was open. A short time, 35 or 40 minutes, are sufficient to smelt the test, for which of course the heat must not be made so high as to melt the copper. This test may be smelted in an iron pot if the ore contains no sulphur. When the smelting is finished, the contents are poured into the iron mould, and the quantity of lead which is obtained, shows the exact quantity of that metal in the ore.

Fig. 106.



When oxide of lead is added to the assay, no test can be made for determining the quantity of lead. The operation is essentialy the same as that above mentioned, and may be performed in a clay or Hessian crucible, in a black lead pot, or an iron pot. The lead thus obtained is cupelled. In all cases where crude tartar is used as a flux, the fire must be kindled above the pots, for if it comes from below, the detonating saltpetre is apt to throw most of the ore out in spite of all precautions. The fire must be low so long as a noise is perceived in the pot; when that ceases the draught-holes may be opened and more fire applied.

In this assay we may use litharge, as in the gold assay; that is, take an excess of litharge and precipitate lead by mixing with it a definite quantity of carbon. But in this case, as in the previous one, a large quantity of silver may remain in the slags. This is of less importance than in the case of the gold assay; still it is sufficient to cause an assay made in a clay crucible to be incorrect. In all these instances, we recommend smelting in an iron pot, with salt and a constant stirring of the mass, and the extraction of the granules of lead by dissolving the cinder. This assay furnishes a more correct result than any other.

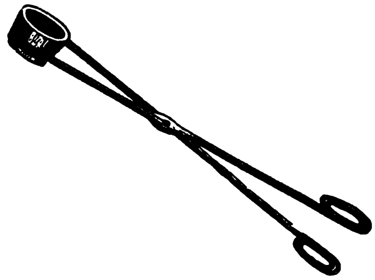
When sulphurets are extensively present in an ore, the operation is in all cases performed with greater facility if the test is smelted with saltpetre only, or a mixtute of saltpetre and litharge, to which carbonate of soda is added. Galena may thus be conveniently assayed for silver, if we pound it with three or four times its weight of saltpetre, and dry carbonate of soda of a weight equal to its own, or the same quantity of oxide of lead. Thus a small quantity of lead is produced which contains all the silver, but not all the gold if any is present. The sulphurets may be also smelted in a clay pot, with just sufficient saltpetre to oxidize all the sulphur and produce no metallic lead. The slag thus formed is covered by a sheet of metallic lead, which in melting down carries all the silver with it. This operation may be correct when executed properly, but it is one of those difficult assays in which the result depends on the skill of the operator. When an assay is performed in an iron pot under constant stirring, all the sulphurets of an ore may be decomposed by litharge; when to this, metallic lead is added and the assay in its fluid state is poured into a hot clay crucible and rapidly melted, so as to accumulate all the metal at the bottom, we may obtain all the silver in the ore, but not all the gold. If a mixture of ore and flux of litharge is so regulated as to form an oxide, the ore never boils on melting; we may therefore in such a case fill the crucible, and cover the top of the ore with pure litharge. As much metallic lead will be produced as is indicated by the amount of sulphur in the ore, which in iron and copper pyrites is considerable. An assay of this kind must be made in the shortest possible time, for the litharge soon eats through a Hessian crucible. Thus we obtain all the silver, and the process is simple and easily performed; the heat necessary is too great for an iron or copper-pot, and if the assay is well regulated the amount of metal produced may by proper attention be considerably diminished.

The first method, that is the assay with metallic lead in the muffle of the cupel furnace, is the most correct, and whenever any doubt exists, it may be resorted to as a final proof of a good assay. It can be applied in all cases where the presence of the precious metals is expected; it is a quick operation, causing but little labor to perform it on an extensive scale. It is the best method of assaying. The use of borax facilitates the operation in some measure, but when more than $\frac{1}{16}$ or $\frac{3}{32}$ of the ore is employed, the assay works slower and is not quite correct.

Cupellation.—This operation is similar to the one described above for extracting precious metals from the ore, with only this difference, that the slags formed are absorbed by the porous mass of the cupel, and thus expose the clean surface of the hot metal to the influence of oxygen. All the metals which can be oxidized under the influence of oxygen and heat, are thus oxidized and absorbed by the cupel. Those which cannot be oxidized, and remain after the application of the strongest heat on the cupel, are called precious metals, in contradistinction from the others which are often called base metals. We have spoken in former pages of cupels, and of the manner of their manufacture, and merely remark here that the material of which the cupel is made has an important effect upon the accuracy of the assay. Under certain circumstances one kind of mass or composition, and under others another kind, is more correct. Whenever lead only is to be removed, the cupel of pure bone-ashes is the best; but when copper, iron, arsenic, and similar metals, are in the alloy, this cupel does not give at first a correct assay, and it is necessary to alloy the first result once more with lead and cupel again. In these instances, it has been found that cupels made of two parts of wood-ashes and one part of limestone-marl, are preferable to those of bone-ashes. In the mode of manufacturing the cupel there is no difference; the ashes must be washed in warm water, as before explained, and the whole operation conducted as above described, with only this difference, that over the cavity in the cupel made of wood-ashes a thin layer of bone-ashes is placed. The cavity of the newly-pressed cupel is for this purpose scratched by a knife, and some bone-ashes sifted over it and firmly incorporated by some strokes of a wooden mallet on the head of the pestle which forms the cavity. To prevent cracks in the concave surface of the cupel, it must be set aside with the cavity downwards, until used.

Cupelling is one of the most interesting operations in metallurgy. We obtain by it at once a separation of the precious metal from the oxidized metal in a perfect form, quantitatively determined. The chief condition of success is, that the newly formed oxides, of which those of lead and bismuth are the only perfect ones, should be absorbed by the cupel. Copper is absorbed also, but not in a large quantity; it is mechanically conducted to the pores, and soon fills the surface of the cavity, after which no more is absorbed. In a limited quantity all the oxides are absorbed by the cupel, but not directly by the mass of the cupel. These oxides are conducted to the pores by the oxides of lead or bismuth. As the latter metal is very scarce and cannot generally be obtained, we confine our remarks to lead only, presuming that in previous operations all the other oxides have been removed. The cupellation is generally performed on a number of tests at once, for it causes as much labor to refine one test as to cupel a muffle full of them. Those specimens which contain gold, platinum, copper, iron, and other substances, are placed farthest into the muffle, where the strongest heat prevails. The tests, which are alloys of pure silver and lead, or antimony, may be cupelled near the mouth of the muffle. If we neglect to attend to this, it may happen that one test is frozen while the heat carries off from the other silver or gold, or both together by evaporation. In all cases we must be provided with a pair of good tongs, such as is represented in fig. 107, to remove any cupel which is finished, or to move a frozen cupel to a hotter place. The cupels are marked with reddle, also the paper in which the test was saved with a corresponding number; these numbers are marked in a book which contains an account of the mineral or metal, whence it comes and to whom it belongs, the amount of ore assayed and the quantity of metal obtained. When the cupels have attained a white heat, the test is gently put into the cavity, but so that the surface is not injured by the cold metal; it is therefore held for a short time over the cupel to heat it. In some instances, assayers fill the cupel with the test before putting it into the muffle. This is not the proper manner, for a cupel may look well when cold, but on exposing it to the heat of the muffle the invisible cracks open, and cause a failure of the assay, by absorbing metal and slag. Before putting any metal in the hot cupel, the latter is closely examined by bringing the eye

Fig. 107.



to the mouth of the muffle, where it is protected against the radiating heat by interposing a pane of glass. If no cracks are visible on the surface, the metal may be placed in the cupel. A cupel will absorb twice its weight of oxide of lead; but it is not advisable to put more than its own weight into it, for an excess of lead will filtrate through the cupel and destroy the bottom of the muffle. The cavity in the cupel should not be too deep, for this causes ashes above the test; besides, the oxide of lead does not easily rise above its level, and a deep cupel works slowly; as the fresh air which enters the muffle and passes over the cupel does not enter it. In most cases, we have an alloy for cupellation in the form of a solid button of lead, which is placed with tongs in the proper cupel. If the test is in fine grains, or in dust, such as a precipitate of gold, it is wrapped in a piece of thin sheet-lead, and put into the cupel. In this latter case it is advisable to melt first a little pure lead in the cupel before putting the test into it. A more correct method of proceeding is, to melt lead and the test together in a clean iron ladle, shake it well to dissolve the gold or silver in the lead, and cast this hot lead into the cupel. A ladle of this kind is represented in fig. 108. It is a useful instrument, and serves frequently to replenish a cupel with fresh lead. In case a test is frozen, the assay would be lost if we did not furnish the frozen cupel with a fresh supply of pure hot lead, which will gather the metal, and afford an opportunity of recovering the test. When all the cupels are furnished with their metal, the mouth of the muffle is partly shut with a piece of tough charcoal; a knotty, well-burnt coal is best suited for this purpose. The lead soon melts, and if the heat is sufficiently strong a cloud of white vapors of lead rises over the cupels. If this cloud is low—that is, hovers over the surface of the cupels—indicates that the muffle is too cold. The mouth of the muffle is then closely shut, and the fire stirred to increase the heat. By a small hole, between the coals at the mouth of the muffle, we may now observe its interior. When the cloud of lead smoke rises about half-way between the roof and bottom of the muffle, the heat is strong enough; we now remove a small coal, and admit more air to the interior. When the heat increases so as to cause

FIG. 108.

the vapors of lead to ascend to the roof of the muffle, the coals at its mouth are removed; by this means the cloud is lowered. If the heat is too high, the hot oxide of lead filters through the cupel, and destroys the bottom of the muffle. It also evaporates silver and gold, whose vapors pass off with those of lead. If the heat is too low, the oxides which are formed do not melt at once and penetrate the cupel; a part of the precious metal is carried with them over and into the pores of the vessel. When the operation is well conducted, the melted test shows a clear white color, with a metallic lustre, and on its surface we observe a constant motion, unaccompanied by any signs of ebullition. When nearly all the lead is thus carefully evaporated, and the test is reduced to a size which contains about two parts of lead to one of silver, the mouth of the muffle is closed once more, and the heat increased. After a few minutes, we observe that the globule becomes quiet, and assumes a clear, mirror-like surface, no motion is perceptible, and around it there is a rose of dark oxides in case the alloy contains any copper, iron, or other refractory metals. If the heat is strong, and no vapors any longer rise, the globule has become clear; we then gradually remove the coal from the mouth of the muffle, and draw the cupels gently towards it by means of a hook of strong iron wire. If we remove the hot cupels directly from the muffle into the cold air, the hot globules are liable to explode, particularly when silver predominates in the alloy. The surface of the globule, under these circumstances, cools rapidly and chills, while the gases which may be within break the cold shell in endeavoring to escape, and throw off the parts already cooled and solid. When the globules are very small, or contain much gold, they will not explode, and the cupels may be removed at once with the tongs.

If the lead which has been used in melting or cupelling is not quite pure; if it contains silver, which most of the marketable lead often does, we take an amount of crude lead, equal to that employed in the assay, and cupel it by the side of its corresponding test. The silver thus obtained from the crude lead is subtracted from the assay, and the difference is the actual yield of the ore in precious metal. If the cupels are not sufficiently large to contain the whole of the crude lead, it is divided into two parts and refined in two cupels; the weight of the globules must be equal, and both are subtracted from the weight of the test specimen.

The operation of cupelling is not difficult, but it requires experience to do it so perfectly as to rely with confidence on the result. In all instances the yield thus obtained by the assay is smaller than the yield on the large scale; this difference is greatly increased by irregular or imperfect work. Cold, or frozen oxide must not by any means be deposited in the cupel. It is therefore advantageous to commence the operation under a strong heat, and modify it in the course of the process. As the test is poor in silver as yet, it will not lose much of the silver by the evaporation of the lead. If the test is poor in silver, the heat may be stronger throughout the operation than if it is rich. The last heat should be strong in all cases but of short duration, to prevent as much as possible the evaporation of silver. If it is found necessary to cool either cupel, it may be done by placing a piece of cold iron or clay beside it. If the whole muffle is too hot, and the removal of the coal at its mouth does not reduce the heat sufficiently, a shovel or a piece of cold iron held within the mufflle will effect it. If the draft into the muffle is too strong, and passes too much air into it, the metal is liable to a rapid evaporation and loss of silver; in this case the draft may be modified by narrowing the mouth of the muffle with a brick. A rapid circulation of fresh air in the muffle always causes a considerable loss of silver. We cannot furnish a better rule for regulating it than that given above; the cloud of lead-vapors should move slowly midway between the roof and the bottom of the muffle. When only a few cupels are in the muffle, these may be moved to those places where they will be exposed to a higher or lower heat. The loss of silver thus caused by evaporation, is small but manifest. Another loss is caused by oxidation, and the silver is absorbed by the cupel with the oxide of lead; a third loss consists of that found in the crevices of the cupel in a metallic state. The latter cause of loss is diminished by having close cupels which are free from cracks and fissures. It is, therefore, not possible to furnish a correct estimate of the loss which may happen in an assay; sometimes it is found to be ·003, at others ·05. All metallic lead contains silver; so does litharge and even sugar of lead, and various other salts of lead are not entirely free from it; the amount is often very small, still it can be detected. All slags from the smelting operations contain silver, and those in which the oxide of lead predominates contain most of it. Those assays in which much lead is used and little metal obtained for cupellation, cause more loss in silver than those in which all, or nearly all, the oxide of lead is converted into metal. The losses accruing from smelting are never so great as those sustained in cupellation.

The color of the cupel shows the kind of metals in the test besides lead and precious metal. Pure lead colors a cupel, of white bone-ashes, yellow, which is often inclined to orange; bismuth does the same. Copper causes a gray coating, which is often reddish or brown; iron produces a black, often brownish, coating: tin causes a gray one and invariably freezing; zinc deposits a yellow powder, and causes freezing; it occasions also a loss in silver by evaporation and by ebullition. Antimony causes a bright yellow color, and in most cases a considerable loss in silver by evaporation; it also causes the cupel to crack, which then absorbs the metal.

In the same manner as ores are assayed and cupelled, the products of smelting operations are smelted and refined. The metals from the furnaces are cupelled at once, if they consist of sufficient lead to admit of it. If the lead contains other metals, it is necessary to melt it in a clay dish with some saltpetre and salt, to remove by oxidization those metals which may interfere with the operation. Slags, or sediments from the furnaces, or condensed vapors from the top of the furnaces, are in all cases treated as an ore; that is, they are melted in a flat dish with metallic lead, the foreign matter vitrified, and the silver thus brought into combination with the lead. The quantity used for one assay may equal that mentioned before; but as these materials are generally poor in silver, it may be found advantageous to increase the test to 100 grains, instead of 60 grains, and melt with the same amount of lead. To the metal from the furnace, an equal weight of pure lead is added for vitrification, in case we suspect the presence of other metals than lead.

Assay of an Alloy.—The silver obtained in the large operation by refining, is never pure. It generally contains lead, copper, and frequently other metals, which on an average amount to from one to four per cent. This refined silver may be tested as to its purity by cupellation. A small piece of silver is cut from the ingot on two opposite sides, so as to have the average of the alloy. One pennyweight, or twenty grains, from each side of the silver bar, will make the test two pennyweights: two of these tests are cupelled at once, each with half an ounce of pure lead. At the same heat, and in the cupels side by side, two tests of lead, each of half an ounce, are refined in order to extract the silver contained in the pure lead from the result of the cupellation. The cupels are heated in the muffle to a white heat, before the lead is put in for the silver test; and when the latter is melted and begins to evaporate, the silver is laid in the fluid lead, and at the same time the two tests of pure lead are placed in their respective cupels. The operation is now conducted exactly as before, and the results compared. Silver, which is contained in coin, or in trinkets, or in plate, may be thus determined; but as in these cases the amount of copper is generally very large, and as oxide of lead will conduct only a limited amount of copper oxide into the pores of the cupel, it is necessary to increase the quantity of lead in cupellation, or remove most of the copper by melting it previously with fluxes, which absorb the oxide of copper. If the amount of copper is not too large, or if it is desirable that the test should be made directly on the cupel, we operate exactly as described above; that is, we melt the lead first, and place the test in it, refining at the same time some pure lead. The quantity of copper alloyed with silver determines the quantity of lead to be used in the assay; if the amount of copper is 10 per cent., 7 parts of lead are sufficient for cupellation; if the copper is 20 per cent., 10 parts of lead are required; for 30 per cent. of copper, 14 parts of lead; and for more copper, 17 parts of lead to that of the alloy are necessary. Pure silver requires actually not more than ·3 parts of lead for cupellation; but, as in assays we cannot expect to find pure silver, we employ at least 3 parts of lead to one of silver. In all cases where copper is alloyed with silver, we never succeed in removing it all by cupellation; from one quarter per cent. to one half per cent. of copper will always remain after the best and most accurate assay. Copper is the only metal which may be brought on the cupel without causing any serious incorrectness; all other metals in an alloy must be removed before cupellation takes place. Native silver, sulphuret of silver, galena, copper pyrites, chloride of silver, arseniuret of silver, and other compounds, may be cupelled directly, or with the addition of lead. When we consider the simplicity of smelting in the flat dish,—that is, the process of vitrification,—and the correctness of the assay made in this manner, we find there is nothing gained in attempting to avoid the smelting of the test. The method by vitrification is perfectly safe, when the necessary corrections are applied.

An assay of silver ores is to all appearances not so very simple, and as the chloride of silver is perfectly insoluble in water and nitric acid, the moist analysis seems to be more suitable to produce a correct estimate of the amount of silver in a mineral or an alloy. This is actually not the case; the moist analysis is by no means simple—it requires by far more sagacity, knowledge, and means, than the assay by way of smelting and cupellation. The chloride of silver is soluble in most of the salts of lead and other metals; less so, however, in those of copper, and also in all chlorides; hence more silver may escape our observation than the loss in cupellation and smelting amounts to. The latter process causes a uniform loss, which we may estimate, after some experience. This is not the case if we operate with the moist analysis; the ultimate result may be too large or too small, we have no means of knowing it. When the operation of the wet assay has not been performed with the most accurate means and skill, the result of the analysis is never correct; and as in metallurgical operations, we cannot pay such close attention to assays as is done in a chemical laboratory, we conclude the dry assay to be decidedly the most preferable way of treating silver ores.

Amalgamation.—Some minerals contain gold, silver, and other metals, which may be amalgamated or combined with quicksilver; we shall speak of this process more extensively hereafter, and allude to it here chiefly as an experimental test, to determine the character of an ore in respect to the large operation. All those ores which contain native metals may be amalgamated; the mercury will absorb these metals and form an alloy in case any affinity exist between them and it. Native gold and silver, chloride of silver, sulphuret of silver and gold, and others, may be amalgamated, provided no metallic lead or copper is present; for these also combine with quicksilver, and may deceive the operator if he is not aware of their presence. The operation as a test or an assay is therefore uncertain; it is also slow, expensive, and difficult.

All, or nearly all, tests must be prepared for amalgamation if we wish to succeed; for we do not know whether substances are present which are injurious to the mercury. The ore or mineral for this purpose, is finely pounded and moistened with about ten per cent. of a solution of common salt; then dried and exposed to a gentle heat, with constant stirring. This operation may be performed in an iron vessel. The sulphur, arsenic, and other volatile substances, are thus partly expelled; the metals, such as copper and lead, are oxidized; the silver converted into chloride of silver, and the gold into the metallic state. The roasted ore is put in an iron mortar, mixed with a little mercury, moistened with warm water, and rubbed by an iron pestle. It requires some hours' diligent labor to combine the precious metal with the mercury, after which, water is poured over the ore, and the fine debris of rock, or oxides of metals, are washed away; this may be done in an iron pan, such as was described in the assay of gold. The operation of washing must be performed cautiously; for the amalgam is generally in the form of invisible globules and easily carried away by water, the use of which when warm facilitates the coagulation of the amalgam. The amalgam thus received may be pressed through a piece of soft leather; but as the mercury always contains some silver or gold, it is not advisable to separate any from it by filtration, if the test has been made with a view to determine the quantity of metal contained in the ore. The better plan is to place the amalgam in the cupel and evaporate most of the mercury; but before all is driven off by the heat, add a certain quantity of lead, melted previously in the ladle, and conduct the operation as any other assay by cupellation.

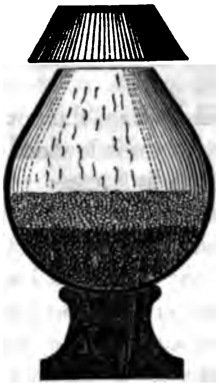
The Globule in the Cupel.—After a successful cupellation the globule is bright, of a rich metallic lustre, and more or less yellow, according to the quantity of gold it contains. It is perfectly round on the upper side and flattened below, adhering to the mass of the cupel. When the globule contains lead, it does not adhere to the cupel, and its surface is dull and shows signs of oxidation. The grain, after a successful cupellation, is laid on a clean steel anvil and flattened with a small hammer, to break loose any cinder which may adhere to its lower side; it is then thrown into a dish of clear water, and washed with a brush. The clean metal is weighed on sensitive scales, which indicate the tenth part of a grain. The silver obtained from the granulated or pure lead, which has been cupelled at the same time with the test, is placed in the scales on the side of the weights; and the weight thus indicated by the scales, is the actual amount of metal in the test.

Separation of Gold and Silver.—Most of the results of an assay contain both gold and silver. This is particularly the case with all our gold ores, and also the silver ores found in the gold region. The separation of these two metals in the dry way, we shall describe hereafter; it is not adapted to secure a quantitative determination on small tests. In all assays of silver ores, it may be reasonably supposed that the amount of silver present is sufficient for the solution of the test in nitric acid. Four parts of silver by weight to one part of gold, are required to make the alloy soluble in nitric acid. Flattening the grain, or drawing it out into a thin lamina on a steel anvil, facilitates the solution of the metal. The silver only is thus extracted from the alloy, provided the nitric acid is pure and free from an admixture of muriatic acid; the gold remains at the bottom of the vessel in the form of a yellowish-brown powder. This is gathered on a clean paper filter, wrapped in a bit of sheet-lead and cupelled. The grain obtained in this cupellation is pure gold, provided the lead does not contain any silver; in that case we must cupel an equal quantity of lead for correction, and determine the assay as described above. If the quantity of gold is so very small that a test on the cupel is impracticable, and if there is any doubt as to its purity, we pour off from the sediment the nitrate of silver, and moisten the residue with a drop of aquafortis, in which the gold dissolves and shows its presence by the yellow color of the fluid; the silver remains. Other metals than gold, such as oxide of iron, cause a similar color in the solution; but we may detect the gold by testing with protoxide of iron, or, which is better still, with sesquichloride of tin in case the quantity is very minute. The latter test is difficult; for the solution must be greatly diluted, the tin solution very clear, and no free hydrochloric acid present: a little nitric acid does no harm, but it is not necessary in a very dilute test. The gold acid solution is, therefore, evaporated to dryness by applying a gentle heat, and dissolved in much water; the solution of chloride of tin is much diluted, and both are placed in a large clean test-tube; the tin is then poured on the gold solution. After shaking the mixture for a while and then suffering it to rest, a bright crimson film of purple of cassius, will appear on the surface in the test-tube. In confirmation of the quantity of silver, the nitric solution of silver may be precipitated by a solution of chloride of sodium, which must be very dilute, to exclude the lead from precipitating with it in case any is present; then filtrate, and cupel the chloride by means of lead. Or if more convenient, the chloride may be weighed; this is however uncertain in its results, because the chloride retains a little water which cannot be expelled.

If gold so far predominates that the alloy is insoluble in nitric acid, aquafortis is applied to the test; this dissolves all the gold when there is not too much silver present. The silver remains now undissolved in the form of chloride of silver, which may be thoroughly dried and weighed. The operation must be performed quickly, and the effect of light on the chloride excluded: 100 parts of chloride are equal to 75·33 parts of metallic silver. If the quantity of silver is so large as to admit of cupelling, the latter operation should be resorted to to determine finally the quantity. We thus find either the quantity of gold, or that of silver, and infer the quantity of the other metal by weighing and calculation.

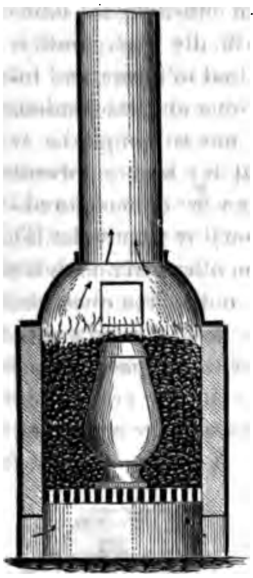
Lead.—A quantitative assay on lead is not so simple as at first sight it appears to be; the oxide of lead is a strong solvent or silex, and where that acid is present it is very difficult to obtain all the metal by a dry assay. The metal is very volatile; so is also its sulphuret and chloride and some other compounds; the application of a strong heat is therefore out of the question. The assay is always performed in a crucible lined strongly with carbon, or in a metal pot as described in previous pages. In all cases, an assay of lead ought to be made in its crude ore. Roasting of lead ore is always tedious, and invariably connected with a loss in metal, which may be from 5 to 10 per cent. We will once more allude to the operation described above. The pot, fig. 109, may be either of copper or iron, because neither of these metals combine readily with metallic lead; if sulphurets or chlorides are to be subjected to the assay, copper pots must be used; and as salt is always employed in this assay, it is advisable to use copper exclusively. An assay is thus very easily made and more correctly than by any other method, but it depends in some measure on the flux used, and the heat applied. The flux is black flux simply, in case oxides and salts are to be assayed; if a sulphuret is under examination, crude flux, that is, crude tartar and crude saltpetre, is used, to which iron filings are added. One weight of ore to four of the black flux is

FIG. 109.



the proportion; or if galena is to be assayed, one part of saltpetre, two parts of crude tartar—argol—and one part of galena, are mixed and finely pounded; to this, fine iron filings, about ⅕ of the weight of ore, may be added. The mixture is placed in the pot, and covered by a layer of salt, for the oxides ¼ of an inch thick, and for galena ¾ of an inch. An air-furnace is not used for smelting, for the draft of it is too strong, and the heat too great; the smelting is done by charcoal exclusively. A furnace for this operation is represented in fig. 110; the pot having a metallic foot is set upon the grate bars directly without a sole-piece of brick; the cover is put on, and coal filled around and over the top of it; the ash-pit is now closed to prevent all access of the air. The fire is applied to the top of the coal, through a small door in the sheet-iron pipe which covers the brick furnace. The latter is about ten inches square or round, and of the same height. The fire sinks thus slowly down in a half hour to the grate bars. By this time the fluxes are perfectly dry in the pot, all crackling noise ceases, and a stronger fire is applied by opening the ash-pit and shutting the door. The furnace is kept full of coal, which is of the size of a hen's egg. A heat of fifteen or twenty minutes' duration will finish the assay, the door is then opened, the cover of the pot removed by a pair of tongs, and if the test is fluid and still boiling, the pot is shut again, and a little charcoal is added if the fire is low down. A few minutes will finish the assay, that is, the flux appears now to be quiet, is perfectly fluid, like water, and may be removed from the fire. The contents of the pot are cast into a hot metal mould, in which all the lead will be found at the bottom, a black cinder above it, and the salt floating as clear crystallized glass on the top of both. When the operation has been well performed there is hardly five per cent. loss in metal, not often more than ten per cent.

FIG. 110.

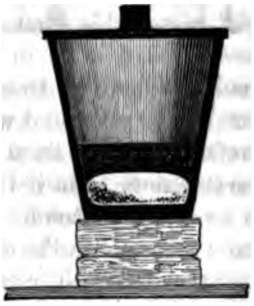


In this case it is immaterial whether we assay slags from the smelting furnaces, glass, or minerals; the treatment is the same, with the exceptions that prepared black flux instead of crude argol, and no iron filings, are used. Litharge from the refining furnaces is treated in the same manner. It is not advisable to put more than one pot at once into the fire, because as soon as a test is perfectly melted it should be removed, notwithstanding others in the same fire may not be ready; this of course causes so much disarrangement that either one of the assays must be doubtful.

We may remark that the success of this assay depends entirely on the flux used. Any borax, lime, or other matter, has a deteriorating effect; if the above-mentioned flux of tartar is not sufficient, the addition of some carbonate of soda will improve its fluidity; yet if too much of the latter is used, other metals such as zinc and antimony may be precipitated with the lead. Salt is a necessary flux in this assay, as it causes the lead to form metal; the chlorine acts on other metals, such as copper and iron, oxidizing them and facilitating the formation of lead, silver and gold.

Assay in Crucibles.—This mode of assaying lead is never so correct as the above, because the evaporation of the metal and its combination with silex and the fluxes cannot be prevented. This assay is always performed in a crucible lined strongly with coal, so that the lead may not pass through the lining and combine with the silicious matter of the pot. Oxides of lead, such as litharge, minium, antimoniates, phosphates, and slags or glass, are pounded finely and mixed with an equal weight of black flux; they are then placed in a crucible, covered by a thin layer of salt, as shown in fig. 111, and exposed, first to a gentle heat for half an hour in an air-furnace, and afterwards for about twenty minutes to a strong heat. By this time the mass is perfectly fluid; it may be perceived by removing the cover. If the assay is still boiling, the pot is covered again, and the heat continued until perfect quietness and fluidity is obtained. Should it happen that the slags are not found to be perfectly fluid, another smelting must be made with the addition of carbonate of soda equal to half the weight of ore.

FIG. 111.



The application of heat must be limited to the shortest time possible, to prevent the evaporation of lead. When the assay is perfectly melted, the crucible is removed from the fire and put on a dry or warm brick, and settled by a few downward smart strokes upon the floor. After the pot is cold, it is broken, and the button of lead, which must be perfectly smooth and of a bluish color, is removed and weighed. In this assay 1,000 grains of ore may be used, but the crucible should never be more than half filled, because the mixture is liable to boil. The proportion of flux to the ore is of some consequence, on account of the carbon contained in the black flux. If the test is chiefly oxide of lead, such as litharge or minium, it is necessary that at least two parts of black flux to one of ore should be used. In this assay crude argol is inadmissible, because it endangers the pot by its combustion; for these reasons we do not know how much carbon may be in the flux. Two parts of any black flux should be sufficient for pure litharge and all other kinds of ore. If the slag is not fluid, which hardly happens by the use of salt, some carbonate of soda is added, which never should be more than equal to the ore. If the ore is very highly oxidized, such as hydrates, and mixed with chromium or iron, manganese, and similar metallic oxides, which require carbon for their partial reduction to protoxides in order to form slags; two parts of black flux are not sufficient for the assay, and it may be found necessary to increase it to four. In this instance it is decidedly better to apply a flux of equal parts of carbonate of potash and carbonate of soda, and also some borax, and take twice the weight of the ore in flux. To this flux sufficient finely-powdered charcoal is added to produce twice the quantity of lead which may be in the ore; one grain of soft charcoal reduces thirty grains of oxide of lead. The ore and all other substances are finely powdered and mixed with water to a stiff paste; this is strongly dried, once more rubbed to a coarse powder, and filled in the crucible. This assay may safely be made in a clay or Hessian crucible; and if the quantity of carbon can be estimated with reasonable correctness, the clay pot is preferable to one lined with carbon, because it requires less time for smelting. But if the quantity of carbon is not exact, if there is too much or too little mixed with the ore, the assay is always more incorrect in the clay than in the coal crucible. The slags near the clay of the crucible are always pasty, and retain more or less lead in small globules which cannot be recovered. This is not the case in the coal-lined-pot, and if grains of metal adhere to the slags, or to the coal, these may be recovered; for the first are soluble in water, and from the latter we obtain the metal by washing. In all cases, the first heat on the pot should be slow and from above, so as to make the boiling, which is modified by a layer of salt, as short as possible. Salt always absorbs a little lead, also iron and other metals; but the quantity of lead thus lost is only a small portion of that which is lost in the cinder when no salt is used. When salt is used, the sides of the crucible are found to be nearly free from globules of lead, which is never the case when only an alkali and borax are used.

The lead obtained in these assays is never pure; it contains always more or less of other metals. When black flux is used it reduces a certain quantity of potash and combines with potassium; this amounts in some instances to two per cent. Copper, tin, silver, and antimony, are found in the lead if the ore contains the oxides of these metals. All other metals combine in small portions with the lead and may be neglected. Zinc combines with lead, but it may be evaporated entirely from it; in this operation, from $\frac{1}{10}$ to $\frac{2}{10}$ of lead, which evaporates with the zinc, is lost. The impure lead may be freed from some of its impurities by melting it with some saltpetre and carbonate of soda in a clay dish in the muffle; this operation is to be conducted at a very low heat, and not extended too far, for much lead may be lost with the other metals. Such refining is never productive of a correct assay; the slags formed contain a little lead, and that also a little of the foreign metals. Silver and copper remain entirely in the lead.

Galena, seleniurets, and arseniurets of lead, are smelted with a flux composed of equal parts of carbonate of potash and carbonate of soda, of which mixture four parts are used. To this mixture, fine iron filings are added equal to about $\frac{1}{3}$ of the weight of ore. The assay may be performed in a flat dish in the muffle, or in a Hessian pot. The test is melted at a cherry-red heat, in which it is perfectlty fluid. The iron added, ought to be very fine or it is liable to mix with the lead. In this test, ten per cent., and if the heat has been strong, fifteen per cent. of lead is lost, while in the assay in the copper pot, not often more than five per cent. of metal is dissipated or remains in the slags. In all these instances it is advisable to rub the ingredients and ore fine, and moisten the compound with water, drying it perfectly before it is put into a crucible for smelting. The fluxes being soluble in water, penetrate the crevices of the ore, and cover the particles; and as the flux is more permanent in heat than most of the lead compounds, it prevents the latter from evaporation. More correct assays are obtained by this mode than by the former. This assay is always more satisfactory when performed in an open vessel under the influence of atmospheric air, than in a closed vessel; and in that case, little or no iron is required to make it succeed well. Galena may be assayed by melting it with pure iron, but the assay is always imperfect; the heat required is so high that in most instances from thirteen to twenty per cent. is lost by evaporation. From ten to twelve per cent. of finely divided iron is needed to perform the operation; if more iron is used not exceeding fifteen or sixteen per cent. the loss of lead is diminished.

Lead and Antimony—A mineral of this composition may be assayed by smelting it simply with 4 parts of carbonate of soda; all the lead is thus obtained, and the antimony remains in the slag. If silver is in the ore, and it is desirable to have it in the lead, this operation will not effect it. In that instance we mix one part of saltpetre with two parts of soda, and take four parts of this mixture to the amount of ore, smelting it in a Hessian or iron pot. This assay furnishes all the lead, all the silver, and the antimony remains in the slags.

The moist analysis may be used to confirm the dry assay. If the latter has been well performed by applying a low heat and fusible flux, the loss in metal may amount, in an average, to ten per cent., and in so far no test in confirmation is required. In the large operation we never obtain more than 85 per cent. of the actual amount of metal in the ore, so that no great difference in the yield of the assay and that of the smelting furnace is perceptible.

Copper.—Assays are always made with particular reference to the operation on the large scale; this is the case with copper more than with any other metal, because the value of the metal is such as to require its extraction from the ore in the purest form. Copper alloys readily with other metals, and it is the object of the assayer both to reduce it and to free the metal from its impurities in order to determine the exact value of the ore. The modes of assaying are different in almost every establishment, and we shall confine our remarks to those which furnish the most correct results, by applying the smallest means. In all cases the first thing done is to make such a sample for an assay as will represent the average value of the whole mass of ore; with this view fragments must be taken from different spots, and mixed and ground together. A part of this mixture is tried, by means of the blowpipe, for sulphur, arsenic and volatile metals. If arsenic or any volatile substance is present the ore must be roasted, and in order to facilitate that operation, a quantity of it, say 1000 grains, is exposed to calcination. This quantity is mixed with sawdust and a little oil, dried, and exposed in a closed Hessian crucible to a red heat, which will remove a large portion of arsenic and sulphur, and other volatile matter. The mass, which is not melted, is, when cooled, triturated, and exposed in a shallow earthen dish, in the muffle, to roasting; the sulphur is by this means, and by constant stirring with an iron rod, almost entirely expelled. If signs of melting are shown in the roasting operation, the ore is again powdered and mixed with a little sawdust, and roasted; this last roasting will drive off almost all the arsenic in case any is present. The mineral is exposed to the heat until all the charcoal is burned away. What remains of the ore is once more ground and mixed with its own weight of calcined borax, one twelfth of its weight of fine charcoal, and formed into a pasty mass by the addition of a little oil. It is then dried, broken, and put into a black-lead crucible for smelting. The crucible is covered by a slab, and subjected to the strongest heat of the air-furnace, which here, as in all other cases, is applied slowly and increased gradually. A heat of an hour's duration is required for an assay; and during the last 20 minutes it should be intense. The crucible is then removed from the furnace and settled by striking it smartly on the floor. When perfectly cold the pot is broken, and the copper is found in its bottom in the form of a button. The color and malleability of the button indicate its purity, and if that is not found to be satisfactory, the button must be refined in a manner which will be described hereafter. This assay is not often found to be correct; the yield is either too low or too high, and for practical or quantitative assays insufficient. The following mode of operation furnishes more reliable results.

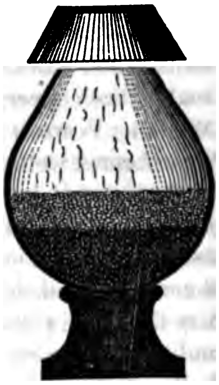
All copper ores which are not oxidized must be roasted, but those which are already free from volatile matter would lose by that operation, and are used in their raw condition. The ore to be roasted is finely powdered and placed on a flat dish, which is rubbed over with reddle, in the heat of the muffle. Two hundred and fifty grains are generally sufficient for an assay, and two assays ought to be made of every ore under examination.

If the copper is mixed with crystallized minerals, such as carbonate of iron, of lime, and similar substances, the heat must be applied gradually, because these crystals explode when suddenly exposed to heat, and throw out the ore from the dishes. Gradually the dishes are moved farther into the muffle, to expose the ore to a stronger heat. All this time the dish which contains the ore has been covered with another, which prevents loss from explosion. When the dishes are red hot, the cover is removed and the ore stirred with a hook of strong, clean iron wire; care should be taken not to bring any ore, by adhesion to the wire, from one dish into the other. The more diligently the ore is stirred, the sooner the operation of roasting is performed. At first the heat is great in the dishes, because sulphur and arsenic burn vividly; it is therefore advisable not to push the dishes too far into the muffle. By degrees the mass assumes a darker color, and the dishes may now be exposed to a higher heat. When the ore appears to be brown-red in the highest heat of the muffle, the dishes are removed, and cooled at the mouth of the muffle; this changing of heat accelerates the process of roasting considerably. Each time the dish is pushed into the muffle again, it is advanced farther in to expose it to an increased heat. When all sulphureous smell has disappeared, and not sooner, the dishes are removed from the cupel and cooled. A little tallow is now laid in each, about the size of a cherry, and the test placed in the muffle again. In burning this tallow off, the remaining sulphur and arsenic are removed, and a white heat will finish the roasting operation. According to the quantity of sulphur, and the quality of metals in the ore, must be the length of time required for roasting. For common copper pyrites one and a half to two hours are needed.

If the powdered mineral under examination is the result of smelting, such as matt or slag, the dishes containing it should not be covered, because in this state it always contains metals which melt readily; and when again melted they make a second pulverization necessary, which is equal to doing the whole work over twice. The operation is in all respects similar to that described, with the exception of a different degree of heat.

To the remaining part of the roasting operation on 250 grains of ore, two ounces of crude flux—consisting of one part saltpetre, and two of crude argol—are added. If this quantity of ore and flux is considered too large, it may be divided into two parts and each one forms an assay; we assume this division to have been made in the following process. The test is placed in a clay or copper pot, as described above, and shown in fig. 112. The mixture of ore and flux is covered by a layer of dry fine salt, about three-quarters of an inch high. This test is treated exactly as the test on lead, in the same furnace, with the exception that a little more heat is applied at the close of the operation. When the test is melted it is poured into a clean, previously heated metal mould, then cooled, and the crude copper liberated from the adhering cinder. About 20 minutes are sufficient to melt this test. The crude copper thus obtained is brittle, and black; it is a mixture of other metals and carbon, but it contains in most cases from 70 to 80 parts of pure metal. This copper must be refined, which is done in the following manner.

FIG. 112.



Refining.—In order to obtain pure metal, a common cupel which is not too deep, is heated in the muffle to a white heat. The button of crude copper previously pulverized, in case it contains lead, is now placed in a piece of paper upon the hot cupel; and in case it contains no lead it is enveloped in a bit of sheet-lead of equal weight to the copper—and when the latter begins to melt, about half as much more lead is added. This test soon melts, and must be closely watched; the heat must not be so strong nor the cupel so deep as in cupelling silver, that a good opportunity of observing the test may be had. The lead will always carry some copper with it into the mass of the cupel, which must be limited to the smallest amount by close watching. When the globule begins to look white, or greenish-white, the test is quickly withdrawn from the muffle, and a drop of water put on the globule to prevent all further losses. The copper will be found soft and highly refined. Some copper is here absorbed by the cupel, but not much when the operation is performed quickly and at a low heat. If we are desirous of ascertaining that loss, a test in confirmation may be made by the side of the real test. For this purpose a quantity of fine copper, equal in weight to the crude copper, is flattened and broken into fine spangles, and enveloped in lead equal in weight to that used for the real test, and in fact the whole operation on this fine copper is performed just as on the crude copper. The loss of the refined copper by cupellation is added to the refined copper of the test, as the approximate loss of the refining process. In this operation it is advisable to work with as little lead as possible; a good performer will work perfectly and easily with half the weight of lead to the copper, and in many cases with even less than that. Much lead causes considerable loss of copper. When an assay is performed well on pure ore, the crude copper contains 80 parts of fine copper in 100 parts; and in cupellation, from 10 to 12 parts of fine copper are lost—so that the actual weight of the refined copper is a good standard for the estimation of the value of the ore, because it fixes this always ten per cent. lower than the actual yield in the smelt-works. This operation requires skill and experience on the part of the operator to perform it well; frequently no pure copper remains on the cupel, all is absorbed by the ashes of the vessel. This is particularly the case with crude copper, which contains more than its own weight of lead. A cupel of fine ashes, and a strong heat, are the best means of securing success.

The foregoing operation appears to be simple in its nature, and in fact is so; the result of the first smelting operation is quite correct, that is, all the copper contained in the ore is in the crude copper, with a variety of other metals. All the lead, silver, and gold is in the button; and when no lead is present, about 15 per cent. of iron is in the crude copper. It is therefore impossible to obtain correct estimates by this method of smelting ore. When any doubt exists as to the results of the cupellation, it is advisable to make an analysis in the moist way on the crude copper to satisfy our mind. The quantity to be operated on is very small in most cases, particularly with poor ores; and we may either dissolve the whole of the crude copper, or a part of it. The analysis is tedious; and if many assays are to be made, as in smelt-works for the valuation of copper ores, it is advisable to experiment by cupellation until success is obtained. For analysis, the crude copper is pulverized, and moistened in a porcelain dish with nitric acid. On applying a gentle heat, the metals are dissolved in this menstruum, which is evaporated nearly to dryness and diluted with water; only carbon, gold, tin, arsenic, antimony, and sulphur remain. The clear liquid is separated by filtration from the residue, and the contents of the latter may be examined. By pouring an excess of sulphuric acid into the liquid all the lead is precipitated as sulphate of lead, which is separated by filtration. This precipitate may be dried and weighed, if it is of any value, to know the quantity of lead. The copper is now precipitated by sulphureted hydrogen from the liquid, which must be done by applying an excess of the precipitant, and operating quickly, because this newly-formed sulphuret soon oxidizes and becomes a sulphate, and is in that condition redissolved. The washing of the sulphuret is performed with warm water. The result thus obtained is roasted and weighed as an oxide of copper. This operation is uncertain in its results, if performed only with usual care and skill. It requires great skill to perform this analysis well, for which reason it is not a common process in practice. If the ore is merely a compound of iron and copper, the analysis is more simple; and the cupellation is still more so, and equally correct. In this case the copper-test is melted with a little saltpetre and argol, on a clay dish in the muffle, and the result is fine copper.

English Process of Assaying.—In Swansea, Wales, where extensive copper smelt-works make many assays necessary, this operation is performed in a manner which is rather expensive; but as the assay is made on a large quantity of ore, it cannot fail to detect nearly its true contents. One ounce, avoirdupois, of ore is selected from an average mixture which has been previously pounded fine and sifted. The ore is put in a flat dish, or a large crucible, which is placed inclined on a coke or anthracite fire, and slowly heated and stirred to expel most of the sulphur, arsenic, and other volatile metals. It is not the object to expel all the volatile matter, but merely to remove most of these admixtures; this operation will require from 1 to 2 hours.

Crude Copper.—When the ore is cooled after roasting, it is mixed with an equal weight, or 15 dwts. of flux. The flux is a compound of 1 oz. 3 dwts. of nitre, 3 dwts. of common glass, 2 dwts. of borax-glass, 2 ozs. of fluor-spar, 1 oz. 12 dwts. of red, or crude argol. These ingredients are finely powdered and well mixed, and preserved in a bottle with a glass stopper. This quantity of flux, or a little more—because some ores do not melt and become fluid with 15 dwts., and may require 20 dwts.—is mixed with ore intimately, and then exposed to a strong heat in a black-lead crucible. On applying the heat gradually, one hour's time is required for the operation in a good air furnace.

The contents of the crucible are poured into a hot and greased metallic mould, then cooled, and the slags knocked off from the button of metal. The button should be of a faint copper color, or, which is better still, shaded with blue. If the button is very rough, too little flux has been used; and if it is very smooth, too much was in the pot; neither of these will furnish a correct assay, for in both cases copper remains in the slags. A white color and smooth surface on the button is never good; the slags are in this case full of oxide of copper and of a stony appearance. This latter appearance is generally produced by an excess of flux or deficiency of carbon. A slag of this kind, when powdered and remelted with a little crude tartar, will produce a grain of metal, which is added to the first button; if no copper is found in this latter assay, the first has been correct. If the first smelting is so far incorrect that the slags look red, or brownish red, it is better to make a fresh assay, for not all the copper can be recovered from these slags. In this operation a new crucible is used for the successive roasting and smelting, for some of the ore may remain in the pot after roasting, which is recovered in smelting. The flux, in this assay, absorbs all other metals, and precipitates chiefly copper, silver, gold, lead, and a little iron; the latter metals must be removed by refining the crude button of copper.

By this assay we obtain a variety of metals in appearance; and according to that appearance, the button is thrown away as useless, or refined. *a*) If the button is very coarse and brittle, like glass, and is black and crystallized, it is rejected, for it never will yield the true contents of the ore. A fresh assay must be made. *b*) When the button looks still finer, and shows some tenacity, but is brittle, it may be smelted again with a flux, similar to that which is used on ores to produce fine copper in the first operation, of which we shall speak presently. *c*) If the button when broken presents a brown copper color, and is somewhat tenacious, but still brittle, it may be considered the result of a good assay. It furnishes in refusing about half its weight in fine copper. This button is remelted in a black pot, covered by a mixture of three parts of white cream of tartar and one part of common salt; and a simple fusion furnishes pure copper from it. *d*) If the button is of a copper appearance, but bluish on the outside, it may be considered as a good ore. This remelted with the addition of argol and salt, and a little carbon, furnishes generally two-thirds of its weight of fine copper. *e*) A button which is white in the fracture, or grayish-white, is never good; it is best to throw it away, because it does not furnish a good assay.

The second smelting generally furnishes crude copper, that is, copper hardly pure. In this operation loss may occur in casting the contents of the pot into a mould; it is therefore generally cooled in the crucible, which is afterwards broken to obtain the button. By trying the button on the anvil with a hammer we soon find if it is fine copper, or if another refining is necessary. In all cases, the copper must be perfectly covered by slags, or loss will ensue from the oxidation of metal.

o make this assay succeed well, the ores under examination should contain some pyrites; if none can be had, eight or ten grains of sulphur should be added, and heated with the ore previous to smelting; because, if no sulphur is present, the slags are stiff, and a loss of metal is the consequence. If the ore is an oxide, or carbonate of copper, and copper pyrites can be obtained, one pennyweight of the latter to one ounce of the first is sufficient to make the slags fluid.

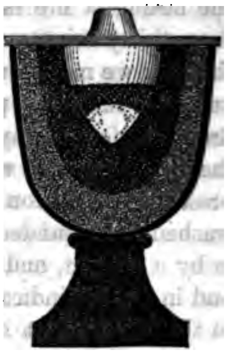
Crude Copper may be obtained on first melting, by roasting the ore thoroughly to liberate it from all volatile matter, in such a manner as has been described in a former operation. The oxide thus obtained from one ounce of raw ore is intimately mixed with 25 to 28 dwts. of the following flux:—3 oz. of refined argol (cream of tartar), 1 oz. 3 dwts. of saltpetre, 10 dwts. of glass of borax, 10 dwts. of common glass, and 6 dwts. of slacked lime; these are well mixed together and rubbed fine. To each assay about 3 dwts. of salt are mixed. At the same time when this ore and flux are smelted in a covered crucible, a little flux, say 3 or 4 dwts., consisting of a mixture of salt and argol, is melted in another pot, and both heated at the same time. The fluid assay is now cast into the hot pot with the melted flux, and poured back into the first; this operation will remove those particles and little globules which may adhere to the sides of the pot, and bring the metal down to a solid button. The crucible is now cooled and broken, and the button of crude copper removed for refining.

The direct way of producing crude copper is not commonly used; it is applied to ores which work hard in the furnace, such as oxides, or ore mixed with heavy spar, or sparry iron. The yield is always small; and the purchaser makes an assay in this way to protect himself against losses in the furnaces; for such ores never yield as well, or work as cheaply, as poor pyrites. Good, easy melting ores require black flux, and do not bear saltpetre in it; on the contrary, all oxidation must be prevented; and if any addition to the first flux is required it is carbon, for the potash resulting from the decomposition of the argol becomes frequently too much for the copper. If too much sulphur is in the first assay, it may be broken and melted once more with argol, which will now produce the desired button, and in all cases a better result than ores without any sulphur. A good first button ought to make eighteen or nineteen grains of crude copper to the pennyweight. And if in melting such a button the slags are too strong, the addition of a very little of the slag from the first operation will cause it to be fluid.

Refining.—The coarse copper thus obtained from either process is not generally pure copper; the refining of this is performed in a small crucible. When the latter is heated almost to a white heat, the copper button is held over it, and when warm, gently thrown into the pot. Over the button, sufficient refining flux to cover it is laid, and on the top of that a little common salt. Refining flux is composed of one and a half pound of nitre; one pound of red argol, and a good handful of salt. These substances are well mixed and finely powdered, then heated in an iron pot and stirred with a red hot iron, so as to form it into black flux. This flux must be saved in well stopped bottles. If the copper is to be very fine, the quantity of saltpetre may be increased to two parts. When the test is perfectly melted, in a closed furnace, which requires only a few minutes, the contents of the pot are poured into a greased mould, and after they become cold the copper will be found fine. It is tried for malleability on the anvil, and its color and fibre are evident when it is broken. The slags from this operation generally contain copper which may be recovered by melting them with fresh argol. The globule of metal obtained from this melting generally contains some iron, but in itself it is chiefly copper. The assays on copper, as well as on silver and gold, always indicate a smaller quantity of metal than the ore yields in the large operation; the purchaser of ore is therefore in no danger of paying too much for the ore if he buys according to the assay. If highly oxidized ores are smelted, a large portion of copper remains in the slags, all of which is not recoverable in subsequent smeltings. The addition of saltpetre to the flux causes similar losses. All the copper may be obtained from sulphurets by the addition of metallic iron, and a flux of four parts of carbonate of soda. Without the presence of iron, no pure alkali produces any copper. Black flux is the best reagent for copper ores, and the addition of salt promotes the formation and quantity of metal. Copper which contains zinc or tin is carefully refined with a flux of salt and saltpetre in the crucible; that which contains gold or silver is cupelled with lead, and has been described under the head of cupellation.

Iron.—An assay of iron ore does not belong to those which are the most easily performed, if we seek the amount of metal exactly. In order to succeed in this operation, we must deoxidize the iron ore, and produce a heat which will melt the metal; and, as iron is extremely refractory, a high heat is often required to make this assay succeed. There is no difficulty in this case to form a fusible slag. The accidental admixtures of iron ore often cause a modification in the composition of the flux; but as a high heat is always required, there is found no difficulty in melting almost any compound. The flux is most commonly pure borax-glass; flint glass, or such glass as contains no iron, may be used with equally good success. The ore is pulverized, and passed through a silk sieve, well mixed with the flux and coarse charcoal powder, and melted in a black-lead, or a coal-lined crucible. On the top of the ore and flux some coarse charcoal dust is brought to prevent the burning of the charcoal before the ore is heated. The pot may be loosely covered by a slab. This assay, when conducted with ability, will produce a fair result from bog ores and hydrates, but not from all other ores. We will therefore describe a more general mode of assaying, which furnishes in all cases correct results.

FIG. 113.



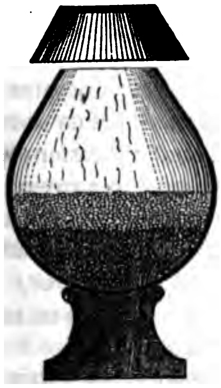
A crucible is formed, as shown in fig. 113, of fire-clay; the foot moulded to it serves as a sole-piece; it is well baked, and in fact treated as any other crucible. In this pot a lining is inserted consisting of one part, in weight, of fine clay, and one of fine charcoal powder, moistened with a little water. The interior of the crucible is lined with this mass and dried; it is about one quarter of an inch thick. A second cement is now formed of two parts of carbon and one of clay; this is moistened, and the whole crucible is filled with it and gently dried. In this last filling, a pattern of wood is pressed while the mass is still damp; this forms the cavity for the smelting of the ore. The form of this cavity is an inverted cone, as shown in the engraving. The pot is covered by a slab made of fire-clay. The ore to be assayed is finely powdered, of which about 120 grains are used; or if a decimal number is selected, 100 grains may form a distinct assay. To 100 grains of ore, from 12 to 25 grains of glass of borax are added, about half as much of chalk, and also from 8 to 10 grains of hydrate of lime. This flux is well mixed with the ore and finely powdered. The mixture is put into the pot, covered with a layer of charcoal powder of hard coal about a quarter or half an inch thick, and then the clay slab or cover is luted firmly to the crucible. Two of these pots may be placed at once in the furnace, but no more, because the heat required in these assays is not so uniform in the furnace as to guarantee the finishing of all the assays in the fire at once, which is necessary if we expect a good result. The furnace is here managed as in all other assays, the heat at first low, is gradually increased, and should be urged at last by a pair of bellows. A heat of one hour's duration must be sufficient for an assay; if a longer exposure of the pot to the fire is required, there is danger of its being melted or broken. With anthracite coal, or coke as fuel, there is no difficulty in maintaining a uniform heat without bellows; but in feeding the furnace with charcoal, it requires constant filling and attention; without blast an assay by charcoal is almost out of the question. From the time when the strongest fire is applied, to the close of the heat, not more than thirty minutes should elapse. In this case we cannot open the pot, we must remove it, when sufficiently hot, from the fire, and cool it. This pot cannot be set, because of its form; we find, therefore, always some small grains of iron in the slag, even if the assay has been well performed. When the pot is cool, it is broken, the button of iron removed and the cinder carefully washed and pounded; the grains of iron are then extracted from it by a magnet, and added to the button, which is now weighed, and in grains indicates the per centage of the ore. The slags in this assay must be perfectly vitrified, glassy, and of a fading green color when seen in thin transparent scales, or through the sharp angles and corners of the solid slag. The iron must be a little carbonized, that is, of a light gray color. It will then indicate the exact amount of iron in the ore. If the slag and iron are not of the described form, the assay is doubtful and of no value; if the slags are stony and the iron dark gray, or the slags stony or vitrified and the iron white, no assay can be considered correct.

Iron ores appear in a variety of forms. We recognize only two classes as having any influence upon the flux in the assay. The above-mentioned flux succeeds in most cases, but when it appears that the ore already contains lime, the lime in the flux may be dispensed with, or the quantity of borax increased. It does not make any difference if the mineral under examination is a magnetic iron ore, specular ore, hydrates of oxide of iron, or hematites of all kinds; argillaceous or sparry ore; slags or glasses, cinders or scales—hammerslag—of iron; all work equally well in this assay. Any iron ore which cannot be melted with this flux in a crucible, or does not melt on being mixed with other kinds of iron ore and assayed with the flux, is useless for the large operation, for it will assuredly not melt in the blast furnace. If the button is of an iron-gray color, but cold-short, the iron in the furnace will be so; and if it is brittle, and the slag smells, when heated and moistened, of sulphuretted hydrogen, or rotten eggs, the ore contains sulphur, and will make red short iron in the blast furnace. In all cases, a journal is kept by the assayer, in which each assay is recorded; this is particularly necessary with assays on iron. The treatment of the ore, flux, crucible, coal and heat are described; the time of smelting, and kind of fuel are entered; and the appearance of the slags, the iron, and all such remarks as are peculiar to the assay are made and noted. The slag must be described very particularly; as, whether it is compact and perfectly vitrified or spongy and porous; stony, transparent or opaque; crystallized or inclined to crystallization; its color in the body, and in the splinters, in reflected light, and in transmitted light. The quality and form of the iron button must be correctly described for reference; whether it is gray, black or white; if crystallized, the forms of the crystals; whether it resists the smart stroke of a hammer on the anvil; and whether it is brittle, or, if malleable, to what degree, &c. In fact, it is not easy to make and record too many observations on an assay of iron.

We want generally the iron only, in an assay of that mineral, and the quantity contained in the test. Matters which may be separated by roasting on the small scale perfectly, cannot be removed entirely in the large operation; it is therefore of little use to roast the ore. Sulphur, phosphorus, and arsenic, may be removed by careful roasting in the muffle, but never by the roasting operations in the furnace yard; it is useless to make good iron in an assay, if it cannot be done in the furnace from the same ore. Water may be expelled by roasting, but the presence of it does not interfere with the smelting operations either on the large or the small scale. A moist analysis of iron ore is practically of no use whatever; it serves for the establishment of theories on fluxes, but the practical metallurgist derives little benefit from such assays. A little time spent on crucible assays is of infinitely more value than the best and most elaborate chemical analysis. It furnishes to the manager of furnaces at once a comprehensive view of the practical value of the mineral under examination. Extensive experiments on fluxes may be made in the crucible, but it is of no use to employ fluxes which cannot be imitated in the blast furnace. When the repeated assay with the above-mentioned flux does not afford a satisfactory result, the mineral examined is worthless as an iron ore.

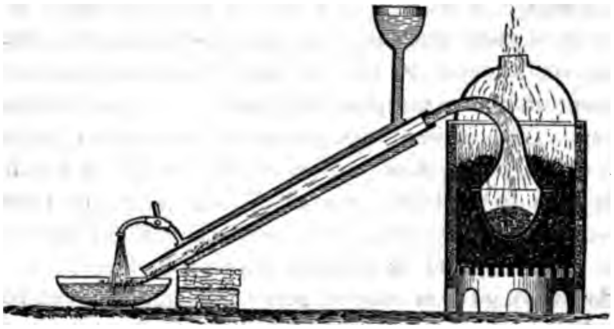
An assay on iron may be performed in a Hessian pot, when the ore is a hematite; in this case it is mixed with coarse charcoal powder in excess, the grains of which are of the size of pins' heads. Such granulated charcoal is formed by cutting it from the face of a round stick of coal, by means of a sharp knife; the fine dust made in this operation is separated from the grains by a sieve. Ore which requires a stronger heat than hydrates, such as red oxides of iron and magnetic ore, may be smelted in a black-lead pot, and mixed with coarse coal as above. Fine coal is inadmissible here, because it hinders iron and cinder from running together. An essential condition in this assay is, that the bottom of the pot be thoroughly hot in order to melt the iron; a large foot-piece is for these reasons inadmissible, and the above-described pot is employed, because it has but a very small sole-piece. In anthracite coal, and in coke fires, a common clay crucible or a plumbago pot, may be used, but the surest way to success is, to line the crucible as described above, and shown in fig. 114.

Fig. 114.



Mercury.—Quicksilver is easily assayed, if we are provided with a proper apparatus. The treatment of materials which contain mercury, in order to obtain it, is in all cases similar. The mineral may be an amalgam or oxide; when sulphurets, chlorides, or similar compounds are to be assayed, a flux must be used which combines with the foreign matter. The most convenient apparatus for assaying mercury is represented in fig. 115. An iron retort of about three inches diameter, which is composed of two parts, is used; the lower part is a cast-iron convex vessel, to which a dome with neck of cast-iron is screwed; the whole is inserted in a common fire-pot and covered with coal; the fire is applied from above so as to heat the dome first, which must be sufficiently hot not to condense the quicksilver. To the neck of the retort a sheet-iron pipe of about half an inch in width and two and a-half feet in length is screwed, which inclines to the ground and reaches down with its mouth over a glass or porcelain basin with water, but does not dip into the water. This iron pipe is surrounded with a second pipe of tin plate, soldered tightly above and below to the iron pipe. At the upper part of the latter pipe a funnel of tin plate is fastened, so that it may serve as a reservoir for water; at the lower end, a stop-cock is soldered to the tin pipe, which regulates the efflux, and so the influx of water. The space between the iron pipe and the tin pipe, which is about ¼ of an inch in width, is thus always filled with cold water, and any vapors of mercury which pass through the iron pipe are condensed and drop into the basin below its mouth. The efflux is so regulated that the water is always cold, and the funnel constantly provided with fresh water. Small quantities of ore, or

Fig. 115.



amalgam, may be assayed in a glass retort, but that is a difficult operation; the glass is liable to break in consequence of the high heat necessary for the assay.

Amalgams, such as those of gold, silver, tin, lead, zinc, and others, are distilled without any addition of flux, or absorbent matter. A mineral which contains quicksilver in one form or another is finely powdered, and mixed with half its weight of metallic iron, if the ore is cinnabar, to which a little black flux or a mixture of lime and carbon is added. When oxides or chlorides are to be distilled, carbonate of potash or soda, equal to half the weight of the mineral, mixed with half that weight of black flux, is added. The retort is unscrewed and the mixture put into the lower part and covered by an extra layer of flux of about a ¼ of an inch in thickness; the latter addition prevents the escape of unreduced mercury. Lime is in all cases a servicable addition to the flux; it facilitates the operation and prevents boiling. All the ores of mercury are liable to boil, for which reason a retort should not be filled more than ½ or ⅓, and the fire invariably applied from above. A strong red heat which does not melt cast-iron is sufficient for driving off all the mercury from any compound whatever. The mercury thus obtained by an assay is never pure; but as the quantity of foreign matter contained in it is very small, we may neglect its presence, and weigh the gathered globules as they come from the pipe, and accumulate in the dish, as if they were the real contents of the ore.

Chromium.—This metal cannot like other compounds, be reduced from its oxides to a metallic condition, at least not with sufficient purity to answer the purposes of an assay. The presence of chrome is found by the blow-pipe experiment most safely, and if it is desirable to know the quantity of metal in the ore, we combine its acid with potash, and determine the weight of chromium by the weight of chromate of potash. This is an operation belonging to the chemist; the quantitative assay of chrome ore is of no value to the metallurgist. The alloys of this metal are of some importance, of which we shall speak hereafter.

Zinc.—The presence of this ore in a mineral is found by applying the blow-pipe test; a quantitative assay is not so easily performed. The best and most convenient way, is to determine the quantity of zinc by an assay of difference. The ore which is to be assayed is finely pulverized, and roasted, so as to expel all sulphur and other volatile matter, which is not so easily performed with blende. Two hundred grains of crude zinc ore are thus exposed to a red heat, which must not be too strong at first, because the ore is very liable to melt, particularly if any lead is present. After repeated roasting and pulverization, we may succeed by diligence in roasting the above amount of ore in three or four hours' time. The ore thus roasted is mixed with about 40 or 50 grains of fine charcoal powder, put in a Hessian crucible, and covered by a layer of coal; a clay slab is then laid loosely on the crucible to protect the interior of the pot against the falling in of coal. The crucible thus prepared is gently heated, dried at first, and then suddenly exposed to a strong white heat, so as to form and evaporate metallic zinc quickly. The residue, after being again roasted in the muffle to remove all the carbon which may remain, shows how much metal has been evaporated; this is set down as oxide of zinc, from which the quantity of metal is deducted. 100 parts of oxide are equal to 80 parts of metal. This operation, simple as it appears, does not furnish a correct assay; if lead, bismuth, and similar metals are present, all of them are evaporated with the zinc, in case their amount is not more than 20 per cent. to that of the zinc. Another mode of assaying, is to mix the ore with borax and lime, the kind of flux used in the assay of iron; and then proceed with zinc ore exactly as with iron ore in smelting, that is, employ a high heat and evaporate all the zinc. This method is objectionable for the same reasons as the previous mode; for all the lead, bismuth, antimony, and even some copper, are entirely driven off with the zinc by the heat.

Assaying zinc ore by distillation, on the principle employed in the large operation, is impracticable, because the metal cannot be gathered correctly. Any assay made in this manner is therefore worthless. Pure zinc ore, which contains zinc, iron, silex, or clay only, may be assayed by the above differential assay with sufficient accuracy in the result. Ores which contain lead and other volatile metals, must be analyzed in the moist way. As this mode of assaying is beyond our limits, we abstain from alluding to it.

Tin.—The assay of tin ore is not difficult, but it still requires some practice to perform it well. This metal is extremely volatile, and as the affinity of its oxide for silex is great, it requires a strong heat to separate it from that substance, and in the mean time its evaporation must be prevented. An assay on tin ore can be made at a low heat, like that of lead, if we melt the ore finely powdered with black flux and carbonate of soda. An assay made in this way is incorrect; for the oxide of tin is soluble in an alkaline slag, and when all the metal is reduced from the slag, the latter becomes too refractory to admit of gathering the tin into a button; it is thefore diffused in small globules through the mass of the slag. The presence of silex is the chief objection to smelting tin ore with a large quantity of alkali; for pure ores, which may be still rich enough for the large operation, will not furnish any tin by such an assay. A crucible lined with pure charcoal, or that shown in fig. 116, is the best for an assay on tin; the presence of silex or clay should be avoided by all means, and the ore freed from that substance as far as possible before smelting. This may be done to perfection, as tin ore is very heavy. An assay performed by these means is useless as a quantitative assay, and a qualitative test may be had with the blowpipe; it is therefore of no use to test tin ore by low heat and alkaline fluxes.

FIG. 116.

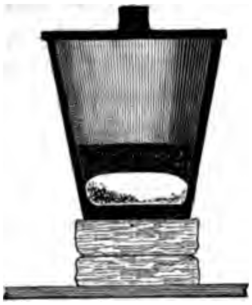
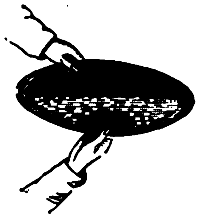


FIG. 117.



Tin ores generally, tin slags from smelting-furnaces particularly, are best treated as follows. The ore or slag is finely powdered, and mixed with $\frac{1}{10}$ or $\frac{1}{8}$ of its weight of charcoal-powder, the grains of which are a little smaller than a pin's head. This mixture is exposed for a couple of hours to the strong heat of the air-furnace, in a well-luted Hessian crucible, lined with charcoal, or a black-lead pot lined with charcoal dust. The ore is thus converted into a brittle, sandy mass of cinder, which is easily broken and changed into a coarse powder; this is washed to remove the coal, and the ore thus prepared mixed with half its weight of carbonate of soda, and exposed to a strong heat in a coal-lined pot. Rich ores will furnish in this way from 75 to 80 per cent. of their metal; the rest remains still in the slags. Poor ores, of 10 and 15 per cent. of metal, do not furnish any metal.

Tin ore may be assayed in the strongest heat of an air-furnace, directly, with a flux of borax and carbonate of soda; an assay of this kind is, however, extremely difficult and uncertain—the results depend here, as in all other instances, on the volatile character of the accompanying minerals, and the quantity of silex present. An assay thus made must be uncertain, for a large quantity of metal may be lost by evaporation. An assay on tin ore is performed in England, which answers for practical purposes. It does not furnish the exact quantity of the metal, but, as the operation on the large scale does not furnish all the tin, the assay is sufficient for establishing the value of the ore.

English Assay.—Of the concentrated and roasted tin ore, 5 oz. are weighed and mixed with one-fourth part, or 1 oz. 6 dwts., of culm—bituminous coal-slack—free from sulphur and sand; or pure bituminous coal grossly pounded. The mixture is put in a blue pot—black-lead crucible—and this exposed to the strongest heat of the air-furnace, for 15 or 20 minutes, or so long as the coal blazes or emits gas. Then stir the mass, and work it by means of an iron rod down into the pot, and melt for 6 or 8 minutes longer. By this time, the metal has become a stiff semi-fluid slag; the crucible is now removed, the slag drawn to one side, and the metal cast into an iron mould which has been previously greased. The slags are scraped out of the pot as clean as possible, into an iron mortar; after pounding and washing it, a great many grains of tin are found in the bottom of the wash-pan, which is of that form used for washing and testing gold ores. These grains and the ingot weighed together, show the yield of the ore in the furnaces; it is below the actual quantity of metal contained in the ore. There is no way of testing this metal for its purity but by the tin-cry; for which reason the melted tin is cast into a shallow mould, in order to obtain a thin bar which may be bent. New pots do not furnish so good a yield as old pots, because, in the first a part of the tin is absorbed and adheres tenaciously to the crucible. Instead of bituminous coal-dust, saw-dust, or brown-charred wood, may be used; mineral coal is the best. From clean, well-washed, and concentrated ore, about 60 parts of metal to 100 of ore are thus obtained—such ore actually contains 70 and 72 of metal; the smelter generally pays only 55 of metal in case the ore, by the assay, shows 60; and if less, he deducts still more than 5 pounds from the 60, or less, of metal. And, as by a second smelting of the slags about one-half of the remaining tin is obtained, the smelter derives from 10 to 12 pounds of metal profit on 100 pounds of ore. The smelter pays thus to the miner about 50 or 55 pounds of tin for 100 pounds of ore; the rest is for his labor.

Cobalt.—An assay of cobalt ore is difficult; in the reduction of the pure oxide to metal there is not the slightest difficulty, but this does not happen to be found native. For these reasons the cobalt ores are treated in the moist way, to obtain pure oxide of cobalt; and, if required, this is reduced to metal. The pure oxide is mixed with the same flux, and treated as the test on iron ore—to which the reader is referred. The cobalt thus obtained contains a little carbon, which may be removed by cementation in a Hessian crucible, and the addition of a little black manganese. Cobalt may be most readily produced in a porcelain tube by heating the oxide, and leading hydrogen or carburetted hydrogen over it; it is then in the form of a coarse powder.

The oxide of cobalt is produced by melting the ore with its own weight of saltpetre; if the ore is pure, once and a half or twice its weight of nitre, to which one part of carbonate of soda is added. This mixture is melted in an iron pot, and poured, after being properly melted, into water and dissolved. The residue is pure oxide of cobalt, if the ore was pure. If iron, silex, or other metals, are present, the sediment of course contains some or all of these substances. In order to purify the oxide from these foreign substances, it is placed in aquafortis, which dissolves chiefly the oxide of cobalt when the acid is limited. The fluid thus obtained is filtrated from the sediment, and precipitated by adding a solution of the carbonate of soda, in small quantities, so as to precipitate the iron first, which is recognized by its crimson color. When the precipitate begins to become rose-colored, the fluid is filtrated from the sediment, and carbonate of soda is added in excess, which now produces oxide of cobalt only.

The presence of cobalt in an ore may be easily recognized by means of the blowpipe; and if a more extensive experiment is required, we may try 8 or 10 dwts. in a crucible. The ore is pounded and sifted, and roasted in a large crucible like copper ore, to which the reader is referred. When the ore becomes red hot, it shows liquid drops on the iron rod by which it is stirred; these appear like melted lead; the pot is now removed and cooled. Two dwts. of this roasted ore are mixed with six dwts. of fine white clay, which has been calcined in order to ascertain if it is free from iron and other coloring matter; or, if such clay cannot be had, pure white sand, finely powdered, may be used. To this mixture of clay and cobalt is added double its weight, or sixteen dwts., of carbonate of soda; the whole is then well mixed and exposed in a covered Hessian crucible to a white heat, all carbon being carefully excluded. The heat may continue half an hour or longer; at any rate the mass must become perfectly fluid. In the bottom of the pot a button of some metal, nickel or bismuth, is generally found, which is thrown out. The slag is found of a dark, blackish-blue color, which, when ground and washed, becomes sky-blue. This is smalt, or cobalt glass.

Nickel.—The source of this metal is chiefly in the cobalt ores; it is, however, found as kupfer-nickel, where it is associated with arsenic. Nickel is more refractory than iron, and requires the strongest heat of the air-furnace. It can be produced, like cobalt, from the pure oxide only. The ore is treated exactly like cobalt ore, in case it is arseniuret of nickel. If any cobalt is present, a better plan is to roast the ore like copper ore, and smelt for cobalt, as above described. The button of metal at the bottom of the crucible generally contains all the nickel combined with sulphur, and some other metals. This button is broken, and exposed to the action of diluted sulphuric acid, which dissolves all the other metals but not the nickel. The remaining part of the button is then exposed, with borax, to a strong heat, which produces a metallic button, consisting chiefly of nickel. In the third part of this work we shall allude to this subject more at length.

Bismuth.—This metal is chiefly extracted from the cobalt ores. The sediment of these ores, or the button obtained by the cobalt smelting, the latter by itself, and the first with a flux of borax, are melted in the muffle in a clay dish, or on a cupel. The oxide of bismuth is more quickly absorbed by a cupel than lead, and of course more rapidly than other oxides. A cupel thus saturated, and freed from the other adhering matter which covers its surface, is then pounded and melted in a coal-lined pot with black flux and some borax, in a gentle heat, and treated like lead. The metal thus obtained is not pure, but sufficiently so to distinguish its character.

Cadmium.—This metal cannot be produced in the dry assay. Of its manufacture we shall speak hereafter. From metallic zinc it is separated by dissolving the metal, and precipitating the cadmium from the solution by pure zinc.

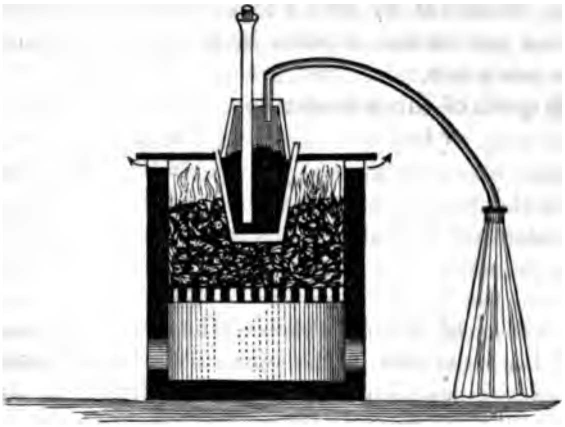
Antimony.—This substance is assayed exactly like lead, but as it is more volatile, the heat must be more limited. With proper attention, the loss caused by evaporation may be reduced to five or six per cent. Most of the metal thus produced contains iron, and as the affinity of antimony for iron is very strong, it is not advisable to melt in an iron pot; the presence of oxide of iron in the flux must also be prevented. It is also necessary to roast, if possible, the sulphuret of antimony, because, if melted with metallic iron, the antimony is never free from iron. The roasting operation is exceedingly slow; but the assay made of the oxide is more safe than smelting the sulphuret in the presence of iron. The oxide thus obtained is mixed with three parts of black flux and one part of carbonate of soda, or any kind of alkaline flux and carbon. The antimony thus obtained contains often five per cent. of potassium, which imparts to it a granulated fracture, instead of a strongly developed crystalline appearance, which is the natural form of pure antimony. No form of a dry assay produces all the metal from the ore, and in no case can the metal be obtained in its pure state.

Other Metals.—Manganese metal, titanium, uranium, columbium, cerium, vanadium, molybdenum, cannot be assayed in the dry way. These metals are of some importance when alloyed with others, and we shall mention their qualities in that relation in the proper places.

Assay of Fuel.—Since in metallurgical operations the chief object of an assay of fuel is to know the quantity of heat which a combustible may produce, and since that heat is in direct proportion to the quantity of oxygen consumed, it is comparatively easy to determine the value of fuel in this respect. For practical purposes the assay is made sufficiently correct with pure litharge; this must be free from minium and oxides of other metals. One part, say ten grains of fuel—this may be wood, or mineral coal of any kind—is converted into fine powder, and mixed with at least thirty times its own weight, or 300 grains of litharge, with some substances, such as pure charcoal or anthracite; forty parts of oxide of lead must be used. The fuel and litharge are well mixed, and put into a large Hessian pot, which must be only half filled with it. Over this mixture a layer of pure litharge is thrown, of about half an inch or three quarters of an inch in thickness, and the crucible placed in a hot furnace under a good cover, to prevent the dropping in of coal; to prevent the upsetting of the pot, the fire ought to be made of coke or anthracite. A heat of ten or twelve minutes is sufficient to melt the mass, which in most cases boils and must be watched; an additional heat of ten minutes finishes the assay, and concentrates the metal which is formed into a button at the bottom of the pot. The crucible is now removed, and settled by a few smart strokes on the floor; after being cooled it is broken. The metal button, which is always found to be remarkably clean, is weighed, and its weight indicates the quantity of combustible matter in the fuel. When pure carbon reduces thirty-three parts of lead from litharge, the difference in the weight of the button shows the inferior value of the fuel under examination to pure charcoal. In this case, the weight of the lead button formed by 10 grains of carbon ought to be 330 grains; if it is less than that, the fuel does not contain so much combustible matter as charcoal.

Particular value of Fuel.—In many instances it is necessary to know the amount of pure carbon in fuel. This is the case when fuel is used in such smelting furnaces, where the ore is brought in immediate contact with the coal. We are here to ascertain the amount of volatile matter and also the amount of ashes. The quantity of volatile matter is easily found by calcining the fuel at a red heat. Wood in pieces, or bituminous or other coal, is loose-

FIG. 118.



ly put in a Hessian pot, upon which a second pot is inverted and luted, as shown in fig. 118, with the difference, that here no pipes are necessary, and simply a hole in the bottom of the covering pot is sufficient. The heat of the crucibles, at first gentle, and then a high red heat, will drive off all the volatile substances, such as water, most of the hydrogen, with some carbon, all other gases which may be in the pores of the coal, and some of the sulphur, in case sulphurets are present. The remaining substance, being almost pure carbon, is weighed, and indicates the loss caused by the evaporation of volatile matter.

Ashes.—In order to determine the residue which is left after the coal is consumed, a certain quantity of fuel, say 100 grains, is used for a test, in small fragments; fine dust does not so well secure a thorough combustion. This powder is placed in a glazed porcelain dish, and exposed to the heat of the muffle. While burning, it is stirred by an iron wire, but not too much, because the ashes may be carried off by the hot gases, if the combustion is violent. It requires in many instances a long time and a protracted heat for this operation; in all cases, however, a low heat will furnish a more correct result than a rapid heat. When the operation is considered as finished, a small part of the ashes is moistened, and if it continues white, or retains its color, it may be pure; but when it turns gray or black, some of the carbon is still there, and the heat must be continued until the ashes show their original color when moistened. The residue thus obtained is weighed, and the number of grains shows directly the per centage of ashes in the fuel. The composition of these ashes has some influence on metallurgical operations. We shall speak of this hereafter.

CHAPTER II.

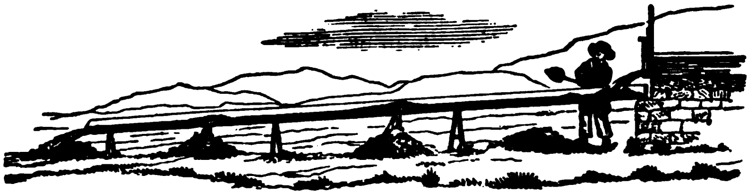
Preparation of Ore by Hand.—When ores are removed or loosened from the vein in the mine, a superficial separation of gangue or veinstone from the ore is performed by the miner. The ore in this condition is brought above ground; it is then once more assorted, and if small parts of veinstone are considered injurious to the smelting operation, they are removed by breaking the ore, and separating it from the rocky matter. This labor is generally performed by small boys, in a sitting position, so that they may be close to the ore and examine it with care, that none which is valuable may be thrown away, and not more rocky matter left with it than is necessary, or which cannot be removed without loss. Ores which contain heavy matter, such as veinstone, should be carefully assorted by hand before they are brought to the machines. Such matter as heavy spar, carbonate of baryta, augit and hornblende, quartz, clay slate, &c., should be separated by hand, for these substances cannot be removed entirely by machinery, and are very troublesome in the subsequent operations. The ores as they come from the mine should be separated according to size and purity; the fine ore, or slack, is thrown by itself, for it is in most cases more impure than lump ore. Pure ore in pieces, is piled by itself; and the doubtful pieces, which contain chiefly rocky matter, are thrown into a separate heap. Such ores as iron are easily assorted; it is of not much consequence if a little rocky matter is mixed with the ore, or a little ore thrown away with the veinstone; but with silver ores this is not so, nor with gold, lead, and ores which appear in the form of sulphurets. These are often scattered through the rock in fine particles, which are hardly visible. It would not make much difference in the results of a mine, if rock which contains pyrites in small particles was thrown away; but there is a peculiarity connected with such pyrites; they contain more precious metal than the densely grouped masses, and are easily purified by pounding and washing; it is therefore well worth the trouble of attending closely to the separation of pyriteous ores. It does not generally take much rock to furnish a ton of pyrites. The same is true of tin and copper ores. In our mines, and operations for assorting ore, we cannot spend much labor on the crude material, because labor is too expensive for that purpose; for this reason iron ores are selected in the mines, and thrown into the furnaces without further attention, in respect to rocky matter. This mode of treating ore answers the purpose in some cases, but not in others; and those ores which are much affected by refractory matter, in the furnace, such as tin, silver, lead and antimony, ought to be carefully selected and purified from it. In this case, four sorts of ore are made of the mineral as it comes from the mine; the pieces of pure ore are thrown by themselves; then lump ore which contains sufficient metal to pay for stamping; then fine dust, and sweepings from the mine and from the yard; and finally rock. The latter, of course, is thrown away, in case it does not pay for converting it into stamp work. The pure ore—fat ore—is either brought directly to the furnace, or to the roasting furnaces; the impure lumps of ore are brought to the stamping mill, and the sweepings are washed by hand. These frequently contain only five or ten per cent. of useful metal, and cannot be worked in the stamping machine, for the ninety parts of rock will not only absorb the ten parts of ore which are in its composition, but will carry away some of the metal from the lump ore which is brought with it to the mill. The stamping mill loses in some cases twenty per cent., and often more, of that ore which is deteriorated by rocky matter; that loss increases with the poorer qualities of ore.

The sweepings are therefore washed by hand, and if they do not pay in that way, they are rejected altogether. Various forms of machines for washing ore are in use. A common wire sieve is often found to be sufficient; the fine ore is taken on a sieve of $\frac{1}{8}$ or $\frac{1}{12}$ of an inch holes, and shaken in a tub full of water, which is supplied by a small current. The fine ore is thus worked through the sieve, and passes into the tub; the heavy particles sink, and the lighter earth is floated off by the current. The ore remaining on the sieve is picked up by hand and freed from quartz and spar, and if pure it is sent to the roast oven. The fine ore in the tub is stirred, and when the latter is nearly filled with mud, clay, and rocky matter, it is removed. If this sediment is rich in ore, so as to pay for washing it once more, it is taken on a finer sieve, and washed again, so as to remove all impurities; if the amount of useful ore does not pay for this labor, the sediment is thrown away.

Another mode of crude washing is performed on ores which are muddy, and which come from a mine in which water and mud are in contact with them. The ore is in this case carried to a stream and thrown into a large flat box, which is supplied with a constant current of fresh water. The mass is stirred with rakes, scrapers, or shovels, and when thus purified it is carried to the yard for separation and roasting. This method is cheaper than the above by means of sieves, still not so economical and perfect as the following.

A long wooden trough, represented in fig. 119, is located so as to have an abundant supply of water at one end, from a river or basin, which furnishes more or less water as may be desired. The trough is in most cases at least 50 feet long, in others 100 feet, and if the ores are covered by a tough clay, it should be 200 and more feet in length. The width of the channel in the bottom is from 10 to 12 inches, and the sides 6 or 8 inches high. It may be made of rough pine boards. The trough is so located that a current of water let in at one end of it moves down to the other; this end, therefore, must be lower than the other. The difference in the level is in some measure decided by the kind of mineral which is to be washed. Minerals are of different specific gravity, and their separation must always depend on the difference of time which they require for subsiding in a fluid. The trough must be so arranged that it can be lowered or raised on its supports, so as to give it more or less descent, particularly at the lower or discharging end. A certain velocity of water is required to move a certain kind of solid matter, and if we reflect on this property of water in motion, and employ it properly, we may separate any kinds of mineral from each other, which have different specific gravities. Common clay, or loam, requires about three inches of motion per second to float it in water; fat clay, about twice as much, or six inches; fine sand, one foot per second; gravel, two feet; broken stones, four feet; slate, four and five tenths feet; pieces of hard rock, such as granite, gneiss, trap, and feldspar, from five to ten feet per second. All these substances are lighter than metallic ores, and it is not difficult to find the inclination of the trough for these various kinds of matter. The head of the trough ought to have at least so much descent as to move all the ore and rock rapidly to a certain distance, at which those portions nearest the bottom may be discharged. This distance must be long in case much clay is mixed with the ores; it may be shorter where debris of rock is to be removed. In all instances, so much water must be led into

FIG. 119.

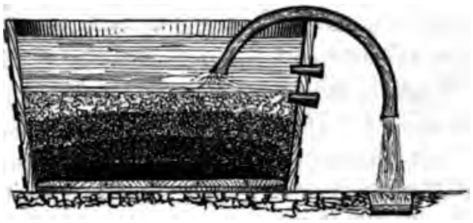


the trough as to cover all the ore, so as to submerge it properly; and should it be desirable to use less water because of its scarcity, the trough may be made narrower, or the fall close to the first discharge-valve may be made less, so as to form a pool, running with a certain amount of velocity over the first aperture. The leading principle in this mode of washing ore, is to liberate clay and rocky matter from it by the rapid motion of the water at the charging place; the ore in rolling down the trough is rubbing loose the loam and sand, which is carried off by the water. The velocity required for this may be great; it must be sufficient to move all the impurities, and the ore also. When the ore has thus been moved so far as to be free from dirt, it is discharged from the trough by a trap-valve in the bottom, and forms a pile beneath, mixed with some impurities. From this first discharge-valve a portion of rocky matter, clay, and earth, is deposited with the heavy ore; these matters are deposited around the heap, and the heavy ore in the centre. In case the ore is not found pure enough it may be washed a second time. In the whole length of the trough there are generally two or more discharge places. Before the muddy water arrives at the end of it all the heavy particles have been passed through these and deposited. The trap-valves are so regulated that the aperture may be made smaller or larger, as the size of the ore and its gravity may require. By varying the openings of these different valves, which must be made of thin sheet-iron, so as to discharge fine ore first, then the coarser, and the coarsest at the last, we may obtain an assortment of ore highly useful. Some of the impurities will be always mixed with the ore, but in discharging the fine from the bottom and moving the coarse onward, the light particles of rock are most of them brought to the end of the trough and here easily discharged.

This apparatus is certainly the most useful washing-machine; it serves equally well for iron ore, or for gold, silver, and lead ores, for alluvial ore, and for stamp work. If the ore after the first washing is not sufficiently pure, it may be washed a second time in a similar trough and with fresh water; but this is hardly required when the first operation has been well performed.

Another method of separating ore from rocky matter, is used in England and other parts of Europe, but not in this country; it is that of the tossing-tub. The ore, either pounded or not, as the case may be, is thrown into a tub with water; and in case it is muddy, it must be frequently stirred so as to prevent any sediment before the impurities are properly loosened from it. When the tub is thus ready for settling, the workman strikes the sides of it with a mallet for 8 or 10 minutes, to hasten the descent of the particles; and then he taps off the water by removing plugs at certain successive heights, or discharges the water by means of a syphon, or inclines the tub and removes the mud and water from the top. In this tub the ore and rock settle in distinct strata, as shown in fig. 120. The best mode of removing the impurities is by means of a syphon, which may be an inch pipe of tin plate, or copper, or lead, bent in a semicircular form; by moving it more or less over the edge of the tub, we may tap any of the upper strata from those below; which operation cannot so well succeed in drawing a plug, or inclining the tub. This mode of washing ore is expensive, but it may be made very useful in particular cases, namely, where the mineral contents are scarce and small, and a large body of foreign matter must be removed in order to obtain them. If we impart to this tub a rotary motion while the water is flowing in, the washing of the ore is performed by the motion, and the mere holding of a fixed rod in the fluid mass will perform the washing operation. When the ore is thus well agitated and the tub set to rest, its contents will settle in the order of their specific gravity and size; the top or light strata are easily removed by tapping them off by a syphon, which may be sunk so deep as to remove all such matter as contains no valuable mineral. To each operation of this kind, an addition of fresh ore may be made, and the sand and earthy matter removed by renewed washings until the stratum of ore at the bottom rises to such a height that a further addition of ore is unsafe. Fresh water only is now used for washing; and the alternate washings, settlings, and tappings, are continued until the ore is entirely

Fig 120.



liberated from foreign matter, or so far at least as the smelting, or other operations require it to be.

Washing by Machines.—To economize labor is the first consideration in erecting washing-machines, for cleaning poor ores and sweepings of the mine and the yard. This alludes more particularly to this country, than to Europe or any other parts of the world; for this reason we cannot use apparatus which require much human labor, or, we must abandon all working of poor ores. The above-mentioned long trough, fig. 121, has obtained the preference already, and is used extensively for washing iron ores, alluvial gold ores, and we hope it may be introduced by the lead and copper mining establishments. In fig. 122, we furnish a drawing of a rack-table used in European smelt-works, not for imitation, but merely to show the principle on which such operations are performed there. A wooden table A, about six, and from that to nine feet in length and two feet in width, is elevated two and a half feet above the floor of the mill, and suspended on two swivels, one at each end; its surface is inclined about five inches. The room below it is divided into various compartments—generally into three. On the slope B, a shovel full of ore is thrown and stirred by a small rake; meantime water is led upon it in a broad and gentle current. The ore is thus washed and the light particles float down the sloping table to the farthest and lowest end, at which they are discharged through a

Fig. 121.

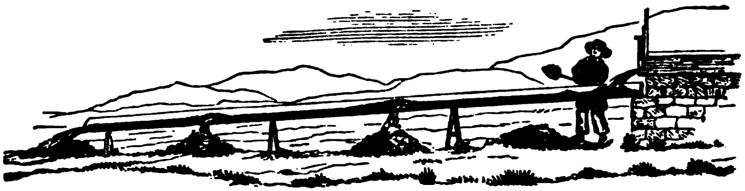
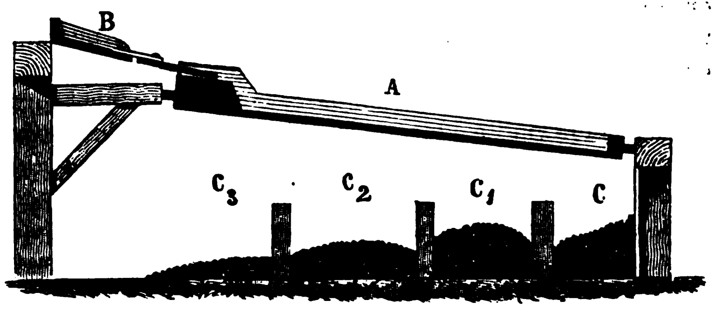


Fig. 122.



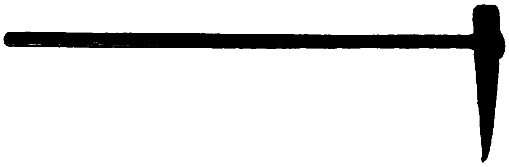
slit or over a projecting-rib, into the last compartment below. The ore thus rolling down the table, is arrested by the friction on it; the heaviest particles settle first and are the highest on the table. When a certain quantity of ore is thus deposited on it, any further addition ceases; a small board, hinged to the feeding-slope, B, is turned over, and the table thus set free to swing around in its swivels. The laborer turns now the table upside down and discharges the ore which is on it, in the compartments below, by which it is divided into various qualities, according to its position on the table. The coarse and heavy ore having been near the highest part of the table, is also found below in the same position. In the last chamber, C, mud and a little ore is found; and in case it will pay for washing, it is again washed. The second chamber, C^1, contains impure ore, which is washed over again. C^2, contains generally good ore, which is removed to the furnaces; likewise the ore gathered in C^3. The length and slope of the table varies according to the nature of the ore; if it is light or fine, the slope is less and its length greater.

Crushing.—Before ores are brought to the smelting-furnaces, or exposed to the roasting process, they are generally converted into pieces of uniform size, or reduced to a fine powder. Iron ores are generally broken by men with hand-hammers, to a uniform size. The form of such a hammer is of some importance to the success of the operation. The one represented in fig. 123, of which both ends are pointed or egg-shaped, is the most common. These hammers are provided with a thin handle, so as to be elastic and break the reaction of the blow. A hickory handle, thinned towards the hammer, is the best. This hammer may be of three or four pounds' weight and provided with a long handle, to be used in a standing position; or it may be small, of one or two pounds' weight, to be used in a sitting posture. In all cases the handle is elastic, so as to form a spring. When ore has been roasted in lumps, and is to be broken after roasting, the hammer has a somewhat different form. One end of it is sharp-pointed and long, so as to pierce the ore and crack it, without

Fig. 123.

forming much dust or fine ore; the other end is blunt, for breaking hard lumps, which resist the effect of the point. Fig. 124,

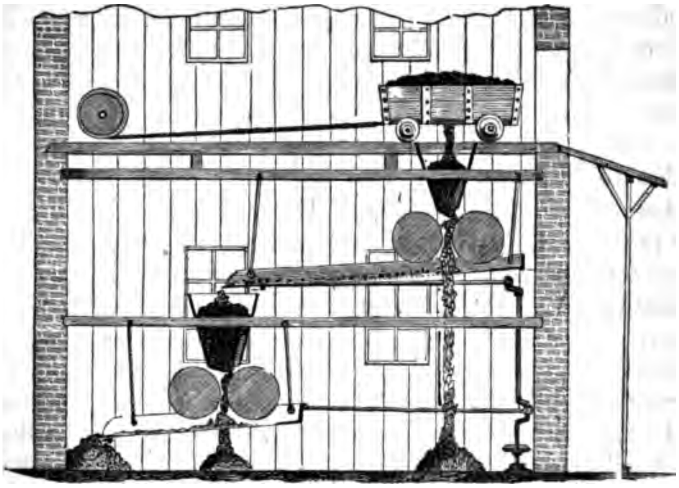
FIG. 124.



shows a nammer of this kind. Both ends must be steeled and hardened.

Rollers.—These machines are not so much used as they ought to be, particularly for some kinds of ore. Rollers do not work on fine ores, but where coarse lumps are used, or ore for roasting is required, these machines do a great deal of service. For breaking iron, copper, silver, lead, and tin ores, rollers form useful crushing machines. In fig. 125, a crushing apparatus consisting of two pairs of rollers is represented; it is not necessary that all machines of this kind should consist of two pairs of rollers; one pair is in most cases sufficient for doing a large amount of work, particularly where the ore used is coarse. The ore is in this instance hauled by the steam engine, or the water wheel, on an inclined plane directly from the mine, in case it is sufficiently pure to admit of crushing; or if it is taken from the yard, either from the cleans-

FIG. 125.



ing house, or from the roast-heaps, or the roast-ovens, the car with its contents of ore is hauled over the upper hopper, and at once emptied into it; thence it runs through the upper rollers into a long sieve, which is set in a rapid shaking motion by means of a crank and the steam engine. From this sieve the ore may pass into a second hopper, and through a second pair of rollers, as is shown in the engraving.

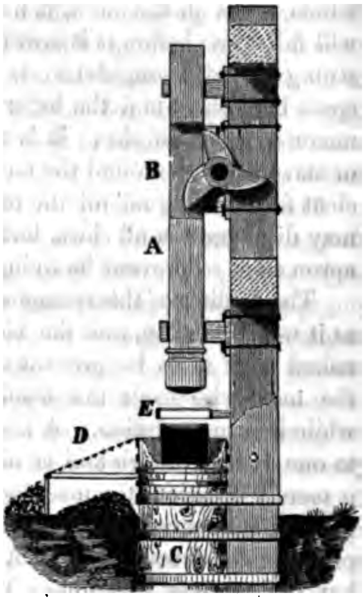
The first hopper must be of sufficient capacity to take a car-load at once, which consists of from ten to twelve bushels. The descent of the ore is regulated by a sliding gate in the hopper; it is necessary that the coarsest pieces should be able to pass the aperture thus formed. The rollers which receive the ore from the first hopper may be close together; in fact, the distance between them is regulated by the biting of the rollers and the size of the ore which is to be formed. In most cases, any size of lumps or of pieces will answer the purpose of smelting. For iron ore, galena, and in some other instances, it is more the uniformity of the size of the pieces which is required than their smallness. The distance between the first or the second pair of rollers is regulated so that they may catch the pieces; and as rollers of small diameter do not bite so well as those of a large diameter, the first pair of rollers are the largest in a machine. The first pair of rollers are generally from eighteen to twenty inches in diameter, the second pair from fifteen to seventeen inches; their length is about sixteen inches. These rollers are provided with strong gudgeons of ten to twelve inches in diameter, with a square coupling at each end, similar to that on rollers in iron works. The manufacture or casting of these rollers requires some attention, that the operation of crushing may succeed well. Some kinds of ore are exceedingly hard, such as pyrites and carbonates of iron, spar, and oxide of tin, also oxide and magnetic iron ore. No kind of cast-iron, or even hardened steel, will resist the carving action of such ore, and the softer and more porous the iron, the more it will be injured. These rollers must consist of a fine-grained, hard charcoal, or anthracite cast-iron. They are cast in chills, and in fact treated like hard rollers for iron mills. The strength of the iron is a secondary consideration in these rollers, for they are hardly ever broken by pressure. Cold-short, close, compact white, or No. 2 iron, which contains phosphorus, arsenic, sulphur, and similar substances, is suitable for this purpose. These rollers make from ten to fifteen revolutions per minute, according to the quality of ore; soft ore may be worked faster than hard ore, and ore which is not to be crushed very fine is run rapidly through the rollers. At this rate, one pair of rollers may grind twenty-five tons of hard ore in a day; and a pair of good rollers will serve on pyriteous ore from four to five weeks. A new pair of rollers will, therefore, grind about 800 tons of ore; they are, by this time, reduced so far in size as to be suitable for the second set of rollers, in case the hard or chilled part of the iron penetrates deep enough to admit of their further use. These rollers would be expensive, if it was necessary that they should be turned exactly true, but this is not the case; the rollers are used as they come from the mould of the founder; the gudgeons, which are comparatively soft, are only turned. The crushing of hard ore is expensive with rollers; and as all ores, and most of the other minerals, are softened by being exposed to a gentle red heat, it may be found advantageous to roast the ores previous to their being crushed, particularly where fuel is cheap.

The sieves, belonging to this crushing machine are square frames covered with iron rods, which are one fourth of an inch round; they are from $\frac{1}{2}$ to $\frac{1}{12}$ of an inch apart, according to the size required; and if the ore is to be fine, a coarse riddle of $\frac{1}{2}$ inch spaces is covered by wire gauze, the meshes having the desired size. All the sieves in a machine are of the same sort, so that ore which once passed the rollers is not subjected a second time to the operation. The coarse ore, which passes over the last or lowest sieve, is returned in cars to the first hopper, and crushed over again, after a certain quantity of coarse ore is passed through the machine. The sieves are set in a rocking motion by a crank. They are a little inclined, and the motion is so regulated that the return of the sieve is quick, and it strikes against a hard, fixed substance, which causes a concussion and throws the ore forward to the discharge.

In some of these machines more than one or two pairs of rollers are used. One roller of a pair is often movable, and held to the other by means of a lever and weight. This arrangement provides against accidents; for, if a hard piece of ore gets between these rollers, it possibly may break one of them if they are immovable, otherwise they may recede and pass the hard piece without causing injury to the rollers.

Stamping.—Crushing by rollers is not applicable in most cases where hard ores are to be reduced in size. Quartz, limestone, spar, hard gangue, compact pyrites, compact magnetic iron ore, slags from the furnaces, fluxes, clay and sandstone, cannot be crushed advantageously by means of rollers—stamps or hammers are employed for this purpose. This operation may be divided into two classes, dry stamping and wet stamping; the first is generally employed to make the coarse fragments suitable for the next, or wet stamping. It is also used for the breaking of stones or fluxes, and the reduction of large lumps of ore.

Fig. 126.

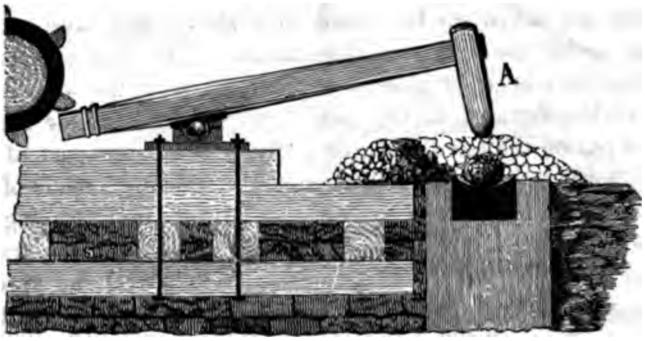


A stamping mill with one stamper, qualified for breaking dry ore, is represented in fig. 126. A solid framework of iron or wood is erected, sufficiently strong to resist heavy concussions, for which purpose wood is better than iron. To this frame a wooden stamper, A, twelve feet in length and eight inches square, consisting of hard oak wood, is so appended as to admit of its being moved freely up and down. A revolving shaft, B, provided with two or three eccentric cams, or lifters, the latter of cast-iron, is put in such a position as to cause the stamper, A, to be lifted successively by the cams. The latter may either work in a slit of the stamper, as shown in the engraving, or may lift it by means of a lifting-bar, as will be described hereafter. The stamper, A, may also be of cast-iron, but this kind are liable frequently to break in consequence of their jarring motion, and side motion of the stamper-head. At the lower end of the stamper a lump of hard and chilled cast-iron is inserted, called the stamper-head; this must be of close-grained iron, extremely hard and strong; a tail of wrought-iron, which is cast in the head, holds it to the stamper. The head may be of 200 or 300 weight; and as the wood is nearly 400 weight, this makes the whole pestle weigh 700 pounds. The head, which is somewhat convex on its lower or working part, strikes on a concave iron anvil; this is a cast-iron block, chilled, and equally as hard as the stamper-head. The anvil is firmly set on the butt of an anvil-log, C, which penetrates some depth into the earth, and is firmly secured in its place by means of iron bands. The anvil is elevated above ground about two feet, and surrounded on all sides, or only on one side, by a screen, D, made of wire gauze, or wire rods; this screen serves as a sieve for the fine pieces which come down from the anvil; the coarse pieces which run down the slope are taken up by means of a shovel, and once more brought under the action of the stamper. The fine ore from under the sieve is either brought to the roast oven, the wash machine, or the furnace, as the case may be. The ore, or rock, which is put on the anvil, is liable to fly, and a large part of it will fall down before it is crushed, unless a screen, E, made of a strong bar of wrought-iron, is bent around the anvil, leaving a space between it and the latter for the passage of the ore fragments of a certain size. It is not necessary to extend the apron or sieve entirely around the anvil; one side is in most cases sufficient for working off all the ore which is pounded. The anvil may discharge on all sides, but a screen conducts the ore to the apron so as to prevent its flying about the place.

The feeding of this stamping-machine requires close attention, as it works rapidly, and the blow of the iron-stamper upon the naked anvil must be prevented by all means; the attention of the man who feeds the machine is therefore closely engaged while it is in operation. A layer of half an inch, and from that to one inch of ore, should be always on the anvil; and if more, it merely occasions the machine to work slower. A feeding apparatus cannot well be appended without much labor; when properly constructed, however, a feeding hopper may be applied, but not without difficulty. We shall speak of this presently. When it is necessary, more than one stamper may be used in this machine; but, as the minerals are pounded only coarsely, one pestle will do a great deal of work. In consequence of the difficulty in feeding this machine, the stamper cannot make more than fifteen or twenty strokes per minute; and if the fragments are to be only of a quarter of an inch in size or more, one stamper will crush a ton of ore per hour. This applies to ore which is easily broken, not to limestone or compact ore.

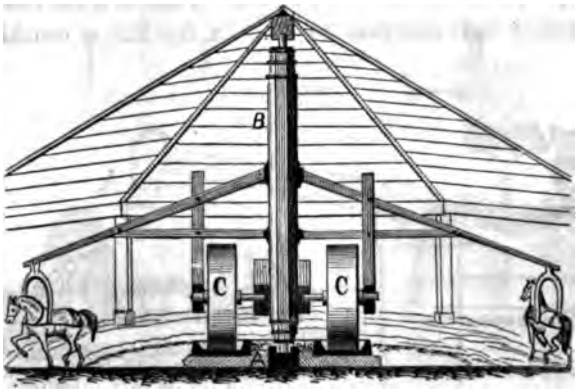
When minerals are merely to be pounded coarsely, such as limestone and other fluxes, or even hard iron ore, either for roasting or direct use, this stamping mill is not calculated to do that work cheaply. In these instances, the mineral is generally broken with hand-hammers. That operation is expensive, particularly for dry limestone or hard ore, and we propose the following machine for that purpose. It has been, and is, in use to some extent, but not so widely as it deserves to be. In fig. 127, a crushing machine is shown which resembles very much a common tilt-hammer. The hammer, A, a cast-iron block chilled at the lower end, works on a cast-iron anvil, which is a little elevated above the ground. This hammer is lifted by a horizontal shaft at the short end of the helve, and may make from 20 to 30 strokes per minute. Its weight is from 400 to 500 pounds, and it has a lift of from 20 to 24 inches. Around the anvil a pile of ore, or limestone, or whatever it may be, is kept constantly, so that pieces are prevented from flying far, and return to the anvil by their own gravity. Two men are constantly required to attend to this machine; one feeds from some heap, and the other draws, by means of an iron rake, those pieces from the anvil which are of the suitable size. A layer of fine ore is always allowed to remain on the anvil. This machine can do a great deal of work if well attended to, and as the breaking of limestone and iron ore is an object of considerable expense in the furnace yard of iron works, this machine may be extremely useful in such cases. For each kind of ore, as well as for limestone, an independent machine must be erected, because the transport of minerals is an object to be taken into consideration here.

FIG. 127.



Mills.—Fire-clay, some kinds of ore, and particularly gold ores, are ground under mill-stones; the machine used is known under the term Chilian-mell in the gold regions. In fig. 128, a mill of this kind is represented. A mill-stone, A, is laid flat on the ground and well secured in its place, in the centre of this is

Fig. 128.



fastened a step for the shaft, B. To the revolving upright shaft, B, one or two grindstones, C C, are appended, which revolve about their axis, and in the mean time round with the shaft, B. This machine is commonly driven by horses, as a common horse-whim, as represented in the engraving. At other times it is provided with gearing so as to move faster than the motion of the horses would permit. The runners, or stones, C C, are in many instances provided with cast-iron rings, chilled; the bottom-stone is also provided with a cast-iron round plate, which forms the bed for the runners. The bed-stone, or bed-plate, is generally provided with a rim or rib to prevent the ore from running off the bed-plate. By means of these mills, which are also driven by water-wheels, or steam engines, an exceedingly fine powder may be formed of any kind of mineral, particularly when it is ground wet. Quite a variety of such mills are in operation, and we shall allude to them in subsequent parts of this book, particularly in the chapter on gold.

For grinding very finely such substances as smalt or cobalt-blue, this mill with head-stones does not answer, and a mill like that shown in fig. 129 is used. This mill is of the form of a common grist-mill, the bottom-stone being placed in a wooden vat, which serves at the same time for the step of the shaft which drives the runner. The latter consists of two halves, or half circles, as shown in fig. 130, lashed together so as to be movable each by itself, but still forming a circle around the shaft. The space between the two halves of the runner serves to attract the coarse particles which may escape grinding, by scraping them from the sides of the vat. When a certain quantity of glass or other substance is thus ground sufficiently fine, it is tapped off by drawing a plug in the side of the mill.

FIG. 129.

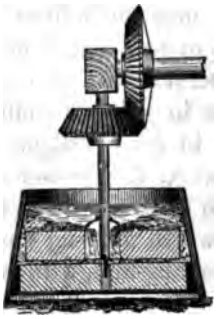


FIG. 130.

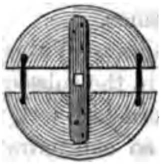
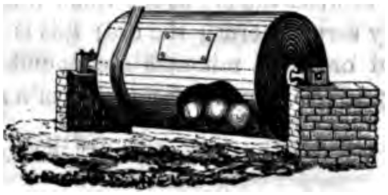


FIG. 131.

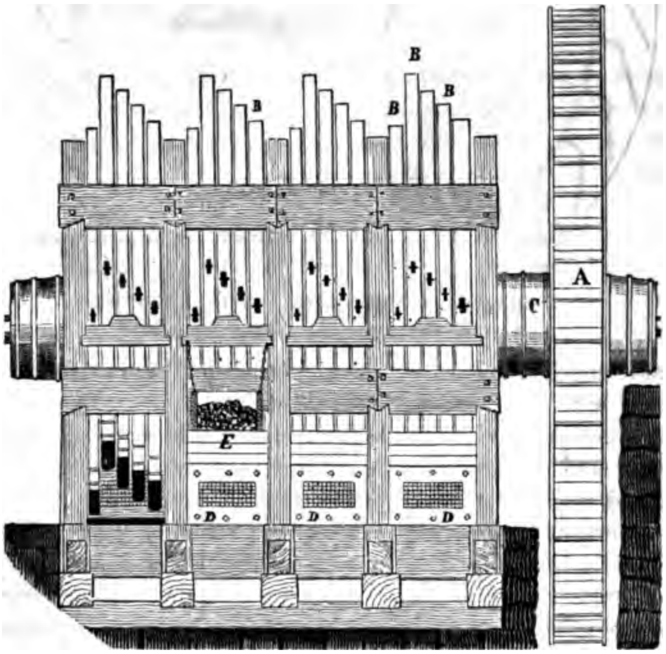


This apparatus may be considerably improved by modifying some parts of it. If we make the runner in one piece, and provide it with a large central space, and arrange it in fact as a common grist-mill, with the exception that the driving shaft does not pass through the bed-stone, and in addition drive the mill with a considerable velocity, the fluid, water, and mineral, assumes a concave form on its surface. It is driven higher at the periphery of the mill than near the centre, and the solid matter as well as the fluid circulates from the periphery to the centre above the runner, and from the centre to the periphery below the runner. The mill thus modified grinds rapidly, and is useful for a variety of purposes, as we shall see hereafter.

Another apparatus for converting mineral substances into small particles, is the revolving cylinder. A cast-iron barrel, fig. 131, of 2 to 3 feet in diameter, and from 1 to 5 feet in length, according to circumstances, revolves about its axis. It is provided with a series of cast-iron balls, or short cylinders, of from 30 to 60 pounds weight each. The balls will crush any substance by their motion, but their action is very slow. The substance to be ground is charged through a door in the periphery, which is screwed tightly to the cylinder. These mills are not very efficient, but are necessary in some instances, namely, when poisonous material is to be ground dry, such as arsenic; or for pulverizing charcoal, or other matter, of which the flying dust is either poisonous or a nuisance.

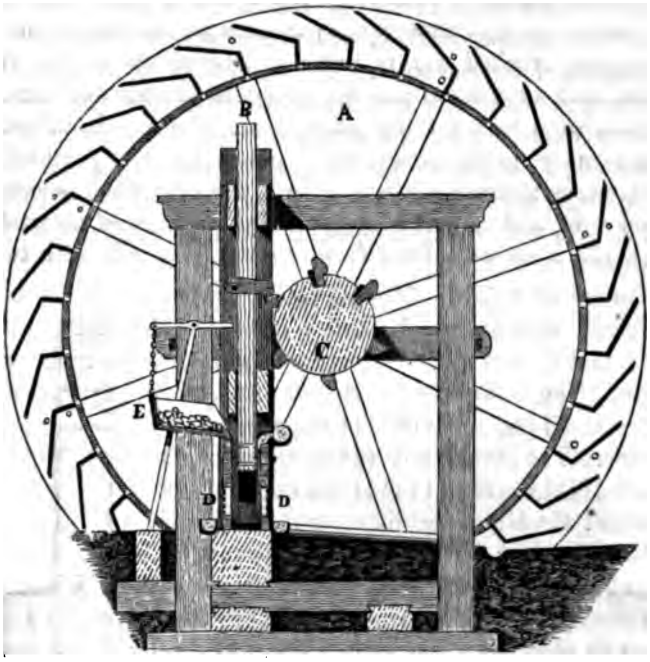
Wet Stamping.—Valuable ores, which may suffer from being used impure in the subsequent operations of smelting or amalgamation, are crushed wet, in order to liberate them from rocky matter, and so concentrate the contents in valuable minerals. The machines used for this purpose are, in some instances, not made to wash the ore at the same time when it is pounded, but merely serve to crush the ore; this is the case when selected or picked ores and minerals are pounded which need no washing. In fig. 132, is shown a front view of a stamping-mill, with twenty stamps, driven by a water-wheel, A, which is directly fastened to the stamper-shaft. The vertical pestles, B B B, &c., are supported by a substantial framework of strong timbers; they are, according to their use, of various sizes; soft minerals require less weight than hard and tenacious minerals. The axle or stamper-shaft, which

Fig. 132.



is generally made of a sound stick of timber, tosses up or lifts the pestles by means of cams or wipers, which are distinctly shown in fig. 133, and when elevated to a certain height drop them suddenly; the force of gravity is the power by which the minerals are crushed. The lower end of the stamper is provided with a cast-iron foot-piece called a stamper-head; this is cast of fine grained hard iron, and chilled in cast-iron chills. Beneath the pestles is a trough of strong timber, into which the mineral is thrown, and into which the stampers drop. That trough is provided with either a cast-iron bottom, or a stone slab, or a bottom of crushed hard rock, or of the ore which is being pounded. Frequently these troughs are provided with cast-iron side-plates which protect the wood, and prevent the flying of the mineral. In some mills three, in others four or five, and even as many as six stampers form one battery, that is, have a trough for themselves. Each battery is provided at one side, or two opposite sides of the square trough with a vertical sieve, D, through which the grains of minerals pass, when reduced to the size required by the holes of the sieve. This sieve may be either a sheet-iron

FIG. 133.



plate, or a plate of copper or brass; it may be made of iron or brass wire, it is immaterial which, provided the holes are so arranged that the grains of mineral do not stop the passage of water and fine sand.

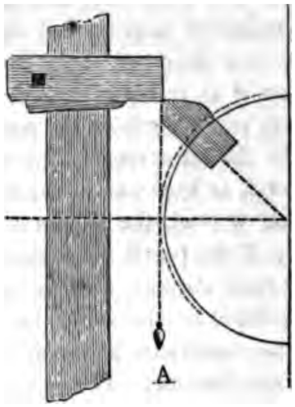
In fig. 133 a side elevation, and partly a section of the stamping machine is furnished. We see here the water-wheel, A, also the frame in which rests one end of the stamper-shaft, a section of the stamper-shaft, C, with its wipers, the pestle, B, and the position of the sieves, D. The wooden pestle is provided at its lower end with some iron hoops to prevent its splitting, from the force exercised by the shank or tail of the stamper-head. The trough, E, is for feeding the machine with ore, which is here supplied by a man with a shovel. In other cases the feeding is effected by a self-feeding hopper, of which we shall speak hereafter.

Number of Wipers.—The wipers in the stamper-shaft are so distributed that an equal number of strokes is made in equal times; that is, that all the stampers of a mill are in a successive motion. The stamper-shaft is best made of wood; iron shafts are too rigid, and occasion the expense of much repair in the machine. The diameter of the shaft can never be too large. A diameter of three feet is not an uncommon size, and certainly not too large; the larger the diameter the shorter may be the wipers, or if the diameter is small the wipers must be long, in order to prevent unnecessary friction. In all cases a large diameter for the extreme wiper-points ought to be provided, even if the shaft cannot be obtained of the proper size. If the number of revolutions of the shaft is known, we easily find the number of wipers in one circle; but this is not the proper mode of determining the construction of the machine. The number of strokes which a stamper is to make in one minute depends on the kind of ore, the weight of the stamper, and the lift of it. These elements must be known before we can determine on the construction of the machine.

The number of strokes of a pestle is dependent on the quality of ore; soft mineral, such as slate, shale, or stratified rock, will bear but a limited number of strokes, because these minerals do not form a strong bottom, and the pestle is very apt to break through and work on the iron sole-plate, the reaction of which soon injures the machinery. From 17 to 20 strokes per minute should be the limit, where the machine is fed by hand; when a self-feeding hopper is appended, from 30 to 40 blows may be made per minute. In some instances this number has been increased to 60 lifts per minute, with hand-feeding; but the consequence is always a rapid destruction of the machines thus overworked. Hard rock, such as graywacke, quartz, and magnetic iron ore, will bear a great deal of pounding; these heavy materials form a strong bottom, and from 50 to as much as 100 strokes may be made, by close attention and self-feeding: with hand-feeding, this number ought to be reduced to one half. The weight of the stampers and the surface they occupy, or the section of the stamper-head, is another element in determining the form and number of wipers. A heavy stamper needs less lift than a light one, and a small section less than a large section. The limits of lift are between 6 and 12 inches; the first for stampers of 500 pounds and heavier, the latter for 300 pounds and less. The lift is in some measure regulated by the size of the ore. If it is coarse, the stroke ought to be longer, but in all instances as short as possible, for there is no advantage whatever in high lifts. The section of a stamper, that is, the lower surface of the stamper-head, is regulated by the kind of mineral and the lift. Soft mineral requires a larger surface than hard mineral, and a heavy stamper may have more surface than a light stamper. The limits are here between 8 inches square, that is, 64 inches surface, and 4 inches square, or 16 inches surface; the first for soft ore or heavy stampers, the latter for hard ore and light stampers. A stamper of wood of 6 × 5½ inches—that is, 33 inches surface, 10 feet long, with a head of 280 pounds, which brings the whole weight to about 460 pounds, 7½ inches lift, and 30 strokes per minute—will convert one bushel of the hardest kind of ore into a considerably fine sand, every hour. With the same stamper, 1¾ bushel of quartz may be converted into coarse sand; and from 1½ to 2 bushels of slate or soft ore can be converted into dust, in the same time, and by hand-feeding. A machine of 24 pestles, of from 380 to 390 pounds weight each, with 10½ inches lift, and 18 blows per minute, crushes about as much as the above machine for each pestle in the same length of time; weight or number of strokes being equivalent to lift. Machines of this kind require one horse-power for each pestle, that is, a horse-power of 33,000 pounds lifted one foot high in one minute. By proper feeding-arrangements the number of strokes may be increased to twice the above number, without increasing the power in equal ratio; the same pestle which makes 20 strokes to one horse, will make 40 strokes with 1·4 horse-power, provided the machine is regularly fed.

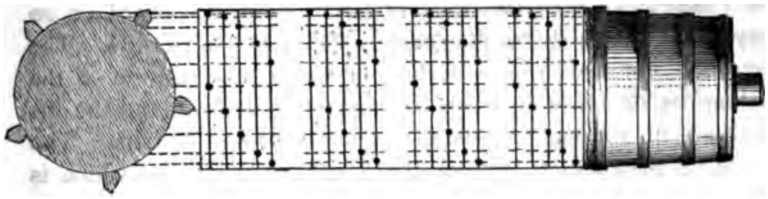
If the number of strokes is thus decided upon, also the lift, and the diameter of the shaft is known, we may determine on the number of wipers and the number of revolutions of the shaft. As a leading principle, the shaft ought to be made to move as slowly as possible, in order to diminish the effect of the concussion resulting from the contact of the wipers and the lifting-bars. For the same reason, the wipers and the lifting-bars should be of wood, at least one of the two; and if one is chosen to be made of iron or steel, the wipers ought to be of that material. The lifting of the pestle consumes a certain part of the time appropriated to each stroke; and as the velocity of the downward motion is modified by the water in the battery-troughs, we may safely assume that twice as much time is used for the descent in water, as in the free air. We point here again to the advantages of short-stroke, in the descent of the pestle in water; the latter limits the force of the pestle, and does so at the rate of the cube of its velocity. We gain therefore very little in force by raising the pestle higher than is actually necessary to break the ore; and it will be found advantageous to increase the weight and limit the stroke as much as possible in all cases where the stamper works in water. A stamper descending 8 inches in the free air may perform that motion in $\frac{1}{12}$ of a second, and in less time; water will diminish the velocity, and increase the time two or threefold; this leaves still a large portion of time for the machine to raise the stamper to the desired height, and it requires but little space between the wipers, to afford the time for descent. We may therefore calculate to have the wipers close together in case the shaft moves slowly. If the length of stroke is determined, and the diameter of the shaft, we mark both sizes on a board, or on paper, in their natural dimensions, as shown in fig. 134. The centre of the shaft is laid in the horizontal prolongation of the lifting-bar, or below it, when the stamper is at rest, and the lift marked in raising the stamper to the proper height. The point of culmination decides the length of the wiper, which is drawn in the direction of the one side, or hypotenuse, of the triangle marked in dotted lines from the centre of the shaft. In drawing the perpendicular A, we obtain the tangent to a circle from which an evolvent to that circle is drawn; that evolvent is the curve for the wiper, provided the bracket is a straight horizontal line. In the periphery of the circle, touched by the perpendicular, A, a string is fastened where the lower corner of the bracket touches that circle, or in fact where the perpendicular, A, touches it. By laying that string over the drawn circle indicated by the dotted line, which may be a round board, and by putting a pencil at the highest point of the lift and fastening it to the string, and drawing towards the centre of the shaft, we obtain the curvature for the wiper, which is the evolvent to the dotted circle. This forms one tappet; the next tappet may be a little below the centre of the shaft, or the horizontal line drawn in the direction of the lifting-bar, in case the shaft moves slowly. If the speed of the shaft is great, the space from the lower line of the lifting-bar to the next wiper must be large so as to afford sufficient time for the pestle to descend before it is touched by the next wiper. There is no necessity for giving more time than is actually required for the descent; no rest of the pestle is needed when once arrived at its lowest position. The distance of one wiper from the other in the circumference of the shaft is thus obtained, and we are now to divide the length of it in such parts that a certain number of wipers shall act on each stamper.

FIG. 134.



The shaft is now turned around on its axis in the gudgeons and marked with concentric rings, two for each stamper, between which the wiper is to be fastened. In fig. 135 this arrangement is shown. If the shaft has five wipers in its circumference, as shown in A, it is divided into as many parts. Supposing there are to be twenty stampers in the whole length, divided into four batteries,

FIG. 135.



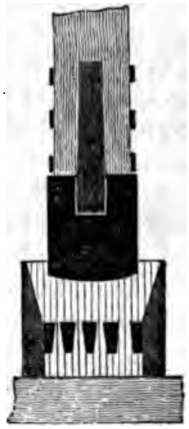
each section of the circle, or one fifth of it, must be therefore divided into twenty parts, because when stamper No. 1 is at rest No. 20 is just moving; in fact No. 1 follows No. 20 in the same interval of time as No. 2 follows No. 1; and all the twenty stampers must make one stroke in each fifth of the circle. These 5 times 20 parts, or 100 parts, are marked over the whole length of the shaft in lines parallel with themselves, and parallel with the axis of the shaft. We may now start with wiper No. 1, in the middle of the first battery, if we choose; with No. 2 in the middle of the second battery, &c., with No. 5 to the right or left of No. 1, or any other arrangement we choose; in fact, it does not matter how the wipers are arranged, if the condition is complied with, that the twenty stampers are lifted in succession while the shaft performs one fifth of a revolution. If five wipers are in the circumference of the shaft, and it is necessary that thirty strokes per minute shall be made by one pestle, the shaft is to make six revolutions per minute. The number of wipers may be chosen according to circumstances, but it is not customary to place less than three in the circumference.

Form of Trough.—The form of the box in which the stampers work is of some consequence on the effect of the machine; too small a trough causes much loss of power, and one too large diminishes the effect of the stamper. From one inch to two inches space should be around the stampers; the latter may be as near together as possible without touching. The box is generally from fifteen to eighteen inches high, formed by cast-iron plates bolted together; or made of strong planks of hard wood, lined with iron plates to a height of six or eight inches. The bottom of the trough is formed of a strong piece of solid timber, upon which, in each battery, a sole-plate of cast-iron from three to four inches in thickness is laid. This sole-piece may be also formed of a hard stone slab, or pieces of hard rock, such as granite or compact iron-ore, wedged in firmly. The sole-piece may be either of iron or of stone; upon it there is always kept a layer of the mineral which is being crushed; this forms a covering to the sole-piece and protects it against the immediate contact of the pestle.

The Sieve, which permits water and pulverized minerals to flow from the stamping box, is fastened vertically to one of the long sides of the trough, opposite to the feeding apparatus, for which openings are provided in the plates forming the box. These sieves, as shown in the drawing fig. 136, marked D, are from eight to twelve inches in length, by five or seven inches in width, and each battery has one. They are made of iron or copper plates, and pierced with small round holes, of which, in many instances, 144 or 160 are within the compass of a square inch; the holes are tapered from within outwards, so as to admit every grain to pass through which has once entered. Brass-wire gauze is also used, and a twilled kind of weaving, which naturally contains more wire and is stronger, is preferable to the plain wire gauze. These sieves, of whatever material they may be made, are fastened to a wrought-iron frame, which is fastened by means of staples and keys to the stamping trough. The adjustment of these sieves is a nice point; their height above the bottom of the trough, has a decided influence on the quality and quantity of the ore pounded; from one and a half to five inches is the extreme limit of the lower edge of the sieve above the bottom. If the sand produced is too coarse, the sieve may be raised and the result is finer work. There are of course limits; to this rule a coarse sieve never making such uniform fine sand as a fine one; but a coarse sieve works much faster in forming the same average size of grain than a fine one. It is therefore of great advantage to work a coarse sieve if circumstances permit, and if a uniform grain is not absolutely necessary.

Open Bottom.—In many instances, particularly when minerals are pounded dry, the bottom to the trough is formed of iron bars, having the appearance of a grate in a stove. The bars are in this case about one and three quarters or two inches square of wrought-iron, and about eleven or twelve inches in length, and resting at each end in a strong frame of cast iron, as represented in fig. 136. The spaces between the bars are from three quarters to half an inch in width, and furnish only a coarse powder. The pestle is large, not often less than seven inches square, so that it may not injure the grate in case it happens to drop on the empty bars. There may here be the same arrangement as above; and a battery may consist of from three to five and more stamps. The stamp-meal of course gathers below the bottom of the trough, and the feeding must be well attended to in order to prevent injury to the machine.

Fig. 136.



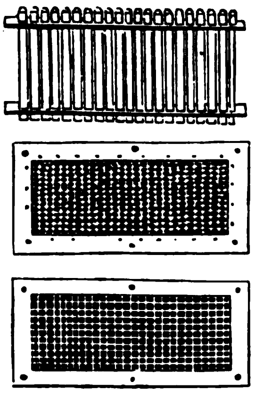
These machines are used to break pure ores, and lumps, which are then washed and treated like small ore, and thus freed from most of their impurities. These stamps serve also for breaking fluxes and those slags which are used as flux, or are broken to obtain the metal which they may contain.

Variety of Forms of Stamping Machines.—Stamping machines consist of a great variety of forms. Many are now built entirely of iron, but so far as we have had opportunities of observing their work, we could not perceive any advantages which they possessed over those of wood; in fact, they work slower than wooden machines, and are subject to much expense for repairs. There are serious doubts as to the iron ever superseding the wooden stamping-mills. The form of a stamping-mill varies according to the kind of work to be done by it, the kind of mineral which is to be crushed, and the quantity to be crushed in a certain time. It is useful for the preservation of the machinery to drive the mill slowly, and for this reason we find the stampers frequently making not more than twenty or thirty blows per minute; whereas a well-built machine may make, without injury to its parts, from fifty to sixty strokes in a minute; and a strongly built frame, with light stampers and short lift, may make eighty and even a hundred strokes in the same time. When the object is to work the ores very quickly and they are hard, such as many kinds of North Carolina gold ores or slags, the stamps should be of a small section, and weighing from two hundred to two hundred and fifty pounds, with a head of four by four and a half inches for such hard ore. Such stampers should be driven at the rate of one hundred lifts per minute, and if their weight is not sufficient to break the ore by a lift of six or seven inches, the downward velocity of the pestle may be increased by attaching a spring to the top of the stamper, which may drive it down with more force. Stampers designed for breaking soft material, such as slaty gold ores, lead ores, pyrites, limestone, and fluxes, coarse sand and gravel, in fact all such materials as do not form a good bottom should have large sections; these must be from six to seven inches square, and often eight inches, and from twelve to fourteen feet in length. Such heavy stampers cannot be driven fast, and their speed seldom exceeds thirty strokes per minute, often only fifteen strokes. The capacity of a mineral for forming a bottom has great influence in determining the speed of the pestles. Quartz, slags, magnetic iron ore, tin ore, pyrites, partly vitrified slate, trap, and all volcanic rocks, form good bottoms, and the pestles may be driven rapidly. Clay, slate, shale, limestone, porous slag, all stratified rock, and sandstone, form soft bottoms, and should have large stampers and slow motion.

As remarked before, the advantages of driving a machine of this kind slowly are considerable; and it is good policy to multiply the stamps, instead of driving them too fast. It saves repairs and expenses in feeding, in case no self-feeding hoppers are applied. A machine of a good construction, and working with little expense in an iron work, may have thirty-two stamps; each of one hundred and eighty pounds, including stamper head; twelve inches lift; fifty strokes per minute, and consumes the power of a twenty-four horse water-wheel. This machine will pound twelve tons of hard material in a day, and convert it into fine sand, such as quartz, pebbles, furnace cinder, iron ore, or limestone. This is a low yield, and the same machine would do twice the work by self-feeding hoppers; it might be safely increased to one third more, by a lower lift and more strokes. We shall furnish more particulars on this subject in the subsequent part of this work, and conclude here by inserting some of the general arrangements in stamping-mills.

If it is the object to form only coarse sand, such as grains of ¼ of an inch in size, to be mixed with fire-clay, or pyriteous ore, in order to free it from rocky matter, lead ores, or silver ores to be freed from blende, furnace cinders, and similar substances; the stamp trough is made spacious, so as to admit of a strong agitation of the water in it. The sieve is in this case composed of rods of iron instead of being of wire gauze or of sheet iron. These rods are either round, of ¼ of an inch in circumference, or square rods of a similar size; the best form is that of a triangle, of which the one side forms the interior surface of the sieve. The sieve is then made as long as the trough, so that the sand from each stamper is discharged at once. The rods are inserted in a wrought-iron, or cast-iron frame, as represented in fig. 137. The side shown, forms the inside of the box. This form of the rods facilitates the discharge of sand,

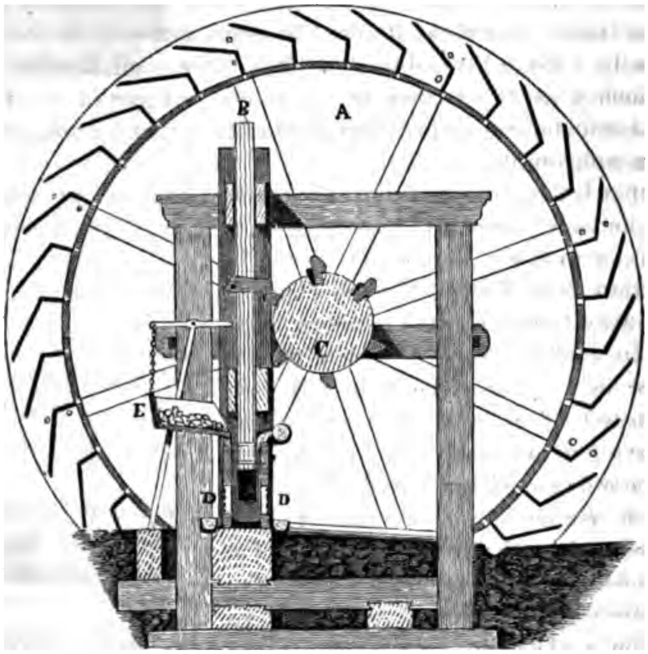
Fig. 137.



which is kept in constant motion by the water in the trough, so that no grains of it can settle at the bars. The two other drawings show a wire grate and a plate grating. The grate is set close to the bottom plate of the trough, often but one inch, and never more than two inches above it. The height of this grate is not often more than four inches. The spaces between the rods are from one eighth to one half of an inch, according to the kind of mineral and the form of the sand to be made.

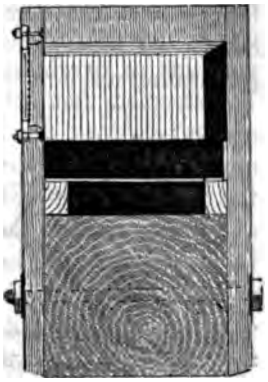
In these machines there are often not more than three pestles in one trough, forming a single battery. They are long and heavy, and often seven and a half by eight inches square. This limitation of the number of stamps in one trough is made necessary on account of feeding, when it is done by hand; in a self-feeding machine the number of stamps in one battery may be increased. The feeding must be performed very regularly, because these machines consume the mineral rapidly. This is facilitated by the shelf, fig. 138, E, which is the whole length of the trough, and inclines about 18° or 20° towards it. In heavy machines of this kind, there are generally two iron bottoms laid

Fig. 138.



one upon the other, separated by a thin board, which prevents the fracture of the lower plate in case the upper should be broken, which may happen if the machine is not sufficiently fed. The lower plate is then four inches thick and the upper one three inches. These plates reach below the end lining of the trough, and are therefore three or four inches longer than the clear length of the trough. The upper plate is also made two inches wider than the lower one, so as to reach the back of the trough opposite the grate, under the lining plate. A section of the trough assumes then the form represented in fig. 139, which requires no explanation. The sides of the trough are not vertical, but inclined about five inches and more; that is, the top of the trough is that much wider than the bottom; the slope, however, is twice as much on the back as on the sieve side. These machines are frequently used for working minerals of various degrees of hardness; and as hard mineral will bear more pounding than soft, the construction should be so arranged, that the lift of the stamps may be altered, by moving either the stamper shaft, or setting the lifting-rod lower. By these means the attendants on the machine are kept at work, and are at the same time enabled to feed it properly.

FIG. 139.



In order to accomplish a great deal of work, these stamps must have an abundant supply of water, which is led either in open troughs or pipes into the trough of the battery. From four to five gallons per minute for one stamper are required, while from two to three gallons for each pestle are sufficient in ordinary cases, and for fine sand. Rapid motion of the stampers also causes the heavy particles to move and float off. Not less than fifty lifts, and not more than sixty-five per minute, appears to be an average velocity.

Each pestle may convert half a ton of hard ore, such as quartz, in one hour's time into sand with grains of one quarter of an inch, that is, work that quantity through a grate or sieve of quarter of an inch slits. As a great deal of fine sand is in the mean time produced, the question is natural, whether a combination of coarse and fine stamping cannot be done to great advantage in the same mill. The abundance of gold ores, and the form in which these appear, make it necessary that a large quantity of ore should be worked in the shortest time, and by the cheapest means. If a coarse battery of five stamps can work tabular quartz, or the average quality of gold ores, which are composed of quartz and slate, this number of stamps may pass one thousand bushels of ore through a quarter of an inch grating in a day. If that sand was led from these stamps over an inclined grate, or fine riddle composed of rods with small spaces, the fine sand and gold would pass through this grate, and the coarse could be shovelled into the hopper of a mill which would convert it finally into fine sand. This operation causes a little more work, because the second machine must be fed by extra labor; but the advantages are such as overbalance all the loss thus occasioned. It may be presumed that half the number of stamps can do the same amount of work which is performed in ordinary cases, when the ore is converted directly into fine sand in one operation. But the greatest advantage is that the precious metal is soon liberated, and not exposed to the action of grinding for a length of time, the gold is obtained in coarser grains or spangles, the gathering of it facilitated, and the loss diminished. This mode of working does not apply to gold ores only, but to other substances; we shall allude to this again in the proper places.

In all instances where minerals, slags, or any substance is pulverized, it must be a leading rule to do as little work as possible; that is, not to pound the minerals finer than is actually necessary in order to separate the impurities and to perform the work in the shortest time possible, and with as little labor as it can be done. In order to succeed in this, the substance is converted into coarse particles, which are of a size sufficient to liberate the valuable metallic contents. If the ore contains native metals, much pounding is hurtful and causes loss in metal, which is converted into fine dust and floated off by the water. This refers particularly to gold, and in fact to all metals. The foreign matter, which consists chiefly of quartz and other similar hard and cutting substances, does more harm to the ore than the contact of the iron stamper-head with it. The pounded matter should be carried off through the sieves as rapidly as possible; and as the metals and metallic minerals are generally heavier than the foreign matter, the first is always less disposed to move than the latter. In order to perform the operation to perfection, the pounded material must be removed from the stamper-trough in the coarsest form possible; the sieve should be laid as low as circumstances will admit. The supply of water must be abundant, and so regulated that the stampers can keep it in constant agitation. The height of water in the battery-trough is therefore a subject requiring close attention. If it is too high, so that the stamper never leaves it, the agitation is diminished; and if it is too low, a considerable splashing is produced, which throws water and minerals over the floor of the mill. With too little water, it is difficult to retain sufficient material below the stampers to form a bottom; the pestles work then on the iron bottom and soon destroy it, and also the stamper-head and the machinery generally, in consequence of the violent concussions. The height of water must be so regulated that no splashing is caused, and the lower edge of the stamper should move above the surface of the water, in order to produce the necessary agitation. A lively motion in the water keeps the grates or sieves clean, and facilitates the removal of the pounded mineral. Too much space between the stampers and the lining of the box is as disadvantageous as too little; it should not be more than three inches and not less than one inch. Large stamps admit of more space than small ones. Small spaces diminish the effect of the pestle, and large spaces diminish the agitation; the proper size must be found by experience; for it is determined by the kind of mineral and the size of the grains which are to be produced.

We have been thus particular on the subject of stamping from the conviction of its great importance in the successful operations connected with metallurgy. The liberation of valuable minerals from foreign matter is undoubtedly the most important branch of that business. The investigation has thus far been of a general character, but we shall particularize it in the particular cases where it is applied.

Final Washing.—The washing of ore, in order to remove impurities, is in most cases a delicate, tedious and costly operation. The leading principle in arranging the apparatus and machinery for this purpose, is the difference in the specific gravity between the various minerals, and also between them and the metals. As not only the specific gravity, but also the size of the grain, and its affinity for water and other minerals, has a decided influence on its tendency to subside, it is evident that the operation of separating minerals by these means is truly one which requires more than common intelligence to perform it well. Iron is by far specifically heavier than quartz, still fine iron filings will float on water, while fine sand sinks directly. Carbon has not the weight of clay, yet fine carbon sinks sooner in water than clay, but not so in air. Gold is by far heavier than silex, but we may observe by means of a microscope a multitude of fine particles of gold suspended in water, while we cannot detect the slightest particle of silicious matter, however fine it may be; the latter will subside more quickly than visible particles of heavy gold. All the metals appear to have a tendency to float in water when in fine particles, some more than others. This is caused by a particle of gas, either air or water-gas, adhering to the particle of metal, which causes it to be light and float, or become suspended. Precious metals appear to possess more of this quality than others. Sulphurets of metal, oxides, salts, and in fact all compound matter, do not manifest it. The size of a particle, and its form, have also some influence in causing heavy matter to subside in water; a large grain will in all instances sink faster than a small one. Observing this as the leading principle in constructing washing-machines, we can arrange the apparatus in such a manner as will best answer our purposes. In no branch of metallurgy is so great a variety of machines and instruments to be found as in that relating to washing-machines. This is easily explained, when we reflect on the great variety of minerals, each of which has its peculiar qualities, rendering the construction of a particular machine in each case almost necessary.

Before entering on the description of these machines we shall make a few general remarks. This operation always occasions a certain loss of mineral, and as it is also expensive and laborious, we must calculate beforehand to what degree of richness the pounded ore can most profitably be concentrated; in other words, at what period of the operation it is most profitable to stop. Too little washing will bring too much foreign matter into the furnace, and too much will cause considerable loss in useful mineral. There are no established rules for this concentration, and in fact never will be, because some furnaces may work an impure ore to advantage, while others hardly work well with pure ore. The kind of impurities has also a decided influence. Heavy spar and quartz diminish the yield of galena in all cases, while calc spar will do it no harm. Lime does not often injure iron ore, while magnesia may affect the operation in the furnace, and also the quality of the metal. In this case, as in the preceding, the rule is, that the less work done on the ore the better. Stamps and washing apparatus must work together in order to produce a favorable result.

In the Sieve.—The pounded ore is in some instances taken from the stamps and washed by hand in a sieve. A common round sieve, or a square one, is suspended on a spring pole over a large tub containing water, which flows in and out constantly. In this sieve about half a bushel of the stamped ore is put at a time, and spread uniformly; in dipping the sieve horizontally, the water passes through its meshes and lifts the ore. The heavy particles will not rise so fast as the light, and on lifting the sieve, the heavy particles will descend more rapidly, or are sooner at the bottom than the light ones. Fine dust will of course pass through and gather in the tub, from which it is removed to wash-machines. On the top of the layer of ore in the sieve that light debris of rock is deposited which is not fine enough to pass through, or float off with the water; this may be removed by hand with a broad spatula of sheet-brass. This part of the ore is thrown into the tub and washed along with the sediment. The ore thus obtained in the sieve is considered pure. When this operation is well performed it is cheap, and qualified to produce satisfactory results. The size of the meshes in the sieve depends of course on the grain of the ore. By this operation a dexterous workman may produce a very pure ore, and the most difficult separations may be performed; it requires experience, however, to succeed well.

If the object is merely to separate the fine matter from the coarse, this is effectually done by passing it through gratings of the proper size; and if we place a series of gratings appended to boxes one over the other, we may obtain a succession of sizes of unequal purity. Metallic ores are generally harder than most of the rocky matter mixed with them, and if the crushing operation has been performed on correct principles, the rocky debris is finer than the ore, and will pass through a finer grating than the particles of the mineral. If to this operation of successive diminution of sizes, we apply the principle of separating by specific gravity, we may succeed in producing a better article and lose less ore in the refuse. In that case a succession of boxes and gratings are employed, and each furnishes a certain quality of ore.

This operation is extremely tedious, and not suitable for our miners; it causes more labor than the best of ores can warrant.

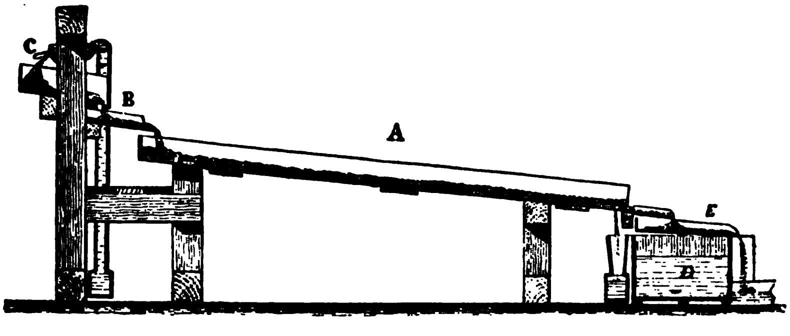
The Labyrinth.—The particles of ore crushed, are at once conducted from the stamps into a system of wooden troughs, or channels, as they come from the stamping-mill. In these channels, which are in most cases about 10 or 12 inches deep, by 15 or 18 inches wide, the ore is deposited successively as its velocity is diminished, and it becomes more or less buoyant. The heaviest particles and the largest are of course deposited first, the finest and lightest float farthest. By these means we may obtain without much labor, a separation of ore and foreign matter, which if not perfect, at least facilitates the subsequent operations. In some instances, we obtain the ore at the farthest end of the labyrinth, instead of near the stamps. Galena, a heavy ore, is very friable, and if it is mixed with hard quartz, heavy spar, or pyrites of other metals, we find but little of it at the entrance of the labyrinth. This mode of separating ore from debris of rock is therefore by no means perfect, but as it causes no expense it is in all cases a useful auxiliary in the operation of purifying the slime, or sliech. The form of these conduits for stamped ore is variously modified, according to the particular qualities of ore, and the capacities of the workmen. The channels are made more or less wide or deep; the current is often interrupted by dams which are formed of a piece of board, so as to gather the ores of a certain grain in one compartment. In some instances the channels are made of various depths, that is, the bottom is laid higher the greater the distance from the stamps, so that when the depth is 8 inches near the stamps, a little further it is 7, then 6, and the last 3 inches; this will cause the light particles to float to the shallow portion, and be there arrested by friction. The length of such labyrinths varies a great deal; for some ores a channel of 20 feet is sufficient, others require 50, and from that to 75 feet in length. In most cases these channels are not in a straight line, but turn and return in various directions, whence the term labyrinth. The returning or turning of a conduit indicates a classification, so that a part of the system may be emptied of its contents while the others are at work.

To succeed well in this operation it is all-important to produce as little dead mass or refuse slime as possible, for this contains always some metal; it is therefore necessary that the ores should be well purified before they are brought to the stamps.

The water with its contents is in all instances carried so far, that all the metallic particles are deposited, and if purified, the water with its foreign matter is conducted out of the building. The more sediment there is in the trough, the faster and more perfectly is the work done; it appears that the attraction of a body of matter in the bottom of the channel facilitates the precipitation; the heavy grains are arrested first, and the light ones, no matter if small or large, roll off with more facility, and are carried farther, than if there was no sediment. In most cases a labyrinth is divided into three channels, of which each produces its particular kind of ore, more or less fine and rich. These different sorts are in many instances once more subjected to this mode of washing; in others they are placed on machines which perform the final separation. In case a further washing is performed, the mass is stirred in one of the compartments by means of a wooden scraper, and a small quantity of pure water is led through it in the mean time, which carries off with it some particles of ore, but mostly foreign matter. The water is conducted through another channel, in which it deposits most of its contents and bears away very little metal. The velocity of water, depth and width of channel, length of the same, and other particulars, must be found by experiments in every case. Too deep channels work irregularly, because the velocity of water and attraction of the mass differs with the quantity of sediment in the trough; ten inches is in most cases too deep. The width depends in some measure on the quantity of ore, but it should not be more than eighteen inches in any case. The length must be regulated by observing the waste which flows off; if it is too rich in metal, which is determined by an assay, the length of the labyrinth is increased by an additional compartment.

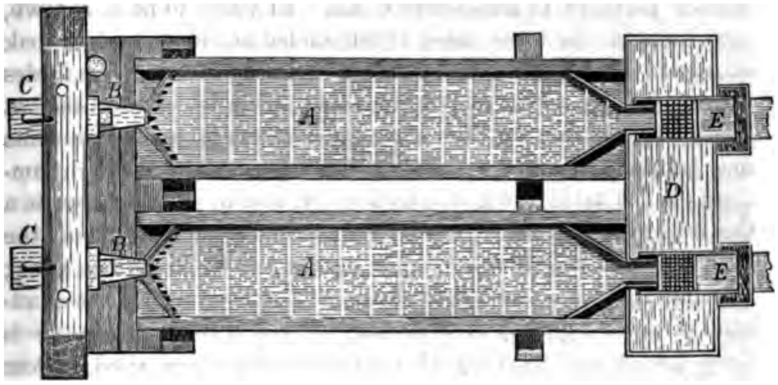
Sweep-tables.—The refuse obtained in the labyrinth is divided into certain parts, distinguished by the amount of useful mineral; those portions which are not yet qualified for the furnace, are subjected to further purification. Various machines are in use for this purpose; but we shall mention only two which are used in some of our smelt works, but which we consider, nevertheless, not the proper ones for us; these are the sweep-tables and percussion-tables. The first are long tables, of which five are generally in one establishment; two serve for washing the richer portions of the ore, and three for the muddy, impure, and fine sediment. Such a table is from 30 to 40 feet in length, or as long as the building will admit of. The width is from 3·5 to 3·75 feet in the clear. They are inclined from 4° to 5°, and form consequently an inclined plane, on which the ore may roll down, when driven by water. At the upper end of the table there is a tub, provided with a horizontal paddle-wheel, into which the slime is thrown, and agitated by the wheel. The tables are composed of oak plank, clear stuff, and perfectly plain and smooth; both long sides are provided with ribs so as to prevent the flowing off of water; at the lowest end is a rib, about ¾ of an inch high, which prevents the heavy ore from floating down, but permits of the light impurities to pass off with the water. At the upper end there is a short table of a few feet in length, which receives a portion of the dissolved ore from the tub, which is let out by drawing a plug; this table forms a kind of box, and is the measure for the quantity of water and ore-sand drawn. When it is filled the tub is plugged up, and that quantity on the table is washed. Clear water is now let on the small table and its contents are gently stirred by a wooden scraper; this sets all the light, and some heavy particles in motion, which flow in a broad but gentle stream down the large table; in this descent the heavy particles settle on the table. When the ore which was tapped from the tub is washed, the contents of the table are swept together by means of a broom and thrown into a vessel, below, through an opening which, is ordinarily shut by a valve. This operation, as will readily be seen, is expensive, and it is a consideration of economy whether the contents of good ore in the impurities will pay the expenses of removal by it.

FIG. 140.



In fig. 140 is represented a vertical section of a sweep-table, in which A is the large table, B a small conduit leading from the trough C, in which the crushed ore is dissolved. D is a trough which receives the ore; E a spout which leads off the muddy water. In fig. 141, the same apparatus is represented in plane.

FIG. 141.



Here are two tables, one beside the other. These are not so long as those mentioned above. They are designed for a more pure and richer ore, and are only from 13 to 14 feet in length. In the bottom of the box which receives the crushed ore from the tub, two plugs, C C, regulate its flowing off over the table, at the head of which we perceive a series of studs forming a grating in a triangular form. These studs are made of wood, and may be turned so that the spaces between them shall be made narrower or wider, according to circumstances, and by these means regulate the uniformity of the sheet of water over the table. The spouts, E E, are elevated above the basin, D, and in removing one or both of the ribs at the lower ends of the tables, the pure contents of the tables are swept into the box, D.

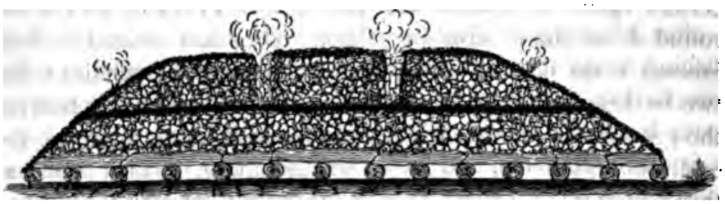
Percussion-Tables.—Between the foregoing and this table, there is no other essential difference than that the latter is suspended on its four corners in iron chains, or iron rods; it is thus movable, whereas the sweep-table is permanent. This table can be set in motion by a revolving shaft, which causes the longitudinal motions to be performed in short intervals and abruptly, so as to produce a concussion against some fixed substance. The water and ore are led from the box over a distributing table, and spread evenly before they arrive on the movable table; the latter is suspended below the first. The ore-sand arriving thus on the gently sloping table, distributes itself uniformly over it. The percussions which the table receives cause the weightier matter to settle first, and accumulate at the upper end; and the light matter settles at the lower end. With the accumulation of the sand on the table, its slope is increased, which naturally causes the heavier particles to float lower down. In order to prevent this, the chains in which the table is suspended at the lower end are shortened by the attendant; this is done by means of a lever turning a long roller above the table upon which the chains wind. By altering thus the inclination of the table, the deposits may be made to settle in regular succession. The middle portions on the table are generally impure, and in order to increase the best quality, that is, the upper portion, the attendant draws sand from the middle towards the top; while doing so, the water meeting it sweeps the impurities down, and a large quantity of sand of second quality is thus converted into first quality. As these tables are generally at least 8 feet long, and from 4 to 5 feet wide, a workman cannot well reach the ore, and is compelled to step on the table in order to perform this duty. The motions of the table are slow, not more than 20 or 25 per minute, and from ¾ to 8 inches throw; and as the sand is heavy and hard, there is no objection to a man standing on the ore. When a sufficient quantity of ore is gathered on the table, it is shovelled off and divided into three kinds, forming heaps which are called No. 1, No. 2, and No. 3. Of these, No. 2 and No. 3 are placed again on the table, and by the same operation converted into No. 1; or if that is too expensive, they are smelted. That part of the ore which flows off at the end of the table, which is generally not provided with a rib, or spout, is conducted into troughs; and if the contents of metal in it are sufficient to pay the expense, this sediment is once more subjected to washing.

There are a variety of washing-machines of curious forms and names in use, most of which are of no interest; the foregoing are the most useful. If the motion of a percussion-table was vertical, instead of being horizontal, there is no doubt the machine would work faster; or if a permanent table is set in vibration by gentle taps from below, that certainly will improve the work upon it. Propositions have been made, and machines tried, to remove impurities from ore by a strong draught of air from a blast-machine, such as a fan-blast. We are not aware with what success these operations have been performed; but as we do not hear of them any longer, we apprehend they are abandoned. No doubt, by this means, ore may be purified; but it is doubtful whether it can be done with such economy as the separation by water. In all these operations of washing, or purification, it must be the aim to work the ore as coarse as possible; fine ore-sand loses always more metal in the waste and water than coarse sand.

Roasting.—This operation is performed on ores either before or after breaking, or crushing them. Ores are roasted before crushing, when it is the intention to remove the impurities with more facility than could be done in the crude state. Native quartz is very hard; but when it is roasted it becomes very brittle, is easily pounded, and easily washed away. This operation on ores is to be performed with great caution, particularly when roasting is done before washing; for most of the metallic ores also become brittle and extremely light when roasted. When ores appear in the form of oxides, such as magnetic oxide of iron, oxide of tin, and a few other oxides, we may roast them and remove the silex to great perfection. But if iron pyrites or galena is roasted, the resulting oxide is easier swept away than the fine quartz which may be in its composition. In some cases washing and roasting are done alternately—this is the case with zinky galena; but this process is imperfect. In general, it is rare that roasting is done before washing, so that the washing almost always succeeds picking and stamping, and roasting follows.

In Heaps.—The operation of roasting is in general executed by various processes, depending upon the nature of the ore, the quality of fuel, and the object to be attained. Roasting in heaps in the open air, is one of the methods most generally applied. This is practised particularly upon iron ore, pyrites, and ores which can bear a strong fire. The operation consists in spreading over a plane surface of ground, billets of wood, or lumps of mineral coal. Such a layer of fuel is generally from 6 to 8 inches thick, and the interstices between the coarse fuel are filled up by chips of wood, wood charcoal, coke, or coal. The ore is now spread over the fuel in a layer of from 12 to 24 inches in thickness, which depends on the kind and the form of ore. Coarse ore, and that which can bear a high heat, may be piled pretty high; but fine crushed ore from the stamps, and ore which easily melts, such as sulphuret, or arseniuret, should not have much coal in a body; the ore is therefore not piled so very high. Alternate beds of fuel and ore are thus formed, and roasting heaps accumulated which are in many cases extremely large, retaining the fire for a long time. In fig. 142, is represented an ore-heap in a form in which it is most commonly put up at smelt-works of this country. Wood is the basis, then ore, then fine charcoal or braize; which alternate layers are continued to such a height as may be convenient. The quantity of fuel to ore is most commonly one inch of charcoal to six inches of ore; in other instances it is one inch of coal to twelve of ore, and even as much as eighteen inches of ore, exclusive of the bottom coal, or wood, and coal-covering. As seen above, the ore is piled upon a network of cord-wood, which is the preferable form for this foundation, because it admits of a lively current of air, which is all-important in this operation. Some chimneys are generally formed in a heap, particularly when the ore is fine; through these the fire is kindled, and when the heat is well distributed in the interior, these are shut and the escape of heat permitted in only a small quantity. The fire must be so regulated that the heat penetrates all parts uniformly, and that no part is more heated than another. The slower the combustion, provided the proper degree of heat is obtained, the better for the ore; if therefore that degree of heat is produced which is considered requisite for the purpose, its further increase is checked by stopping all draft-holes. Too little fuel is injurious to roasting, as well as too much; the proper amount can be found by experience only; no rules can be established on the subject.

FIG. 142.



For roasting in heaps many modes of operation are in practice in Europe. There we see heaps as high as houses, the fire being in constant action for at least twelve months. We also meet with skilfully arranged mounds for roasting, such as in the Hartz mountains of Germany. These variations in the mode of roasting are not adopted here, and appear not to be suitable. Wood is generally cheap with us, and labor and capital high; and as the above form of pile requires more wood and less labor than the German method, also less capital than the English, as practised in Wales on iron ores, it is natural that it should be the most prevalent in this country.

In Mounds.—The difficulty of managing the fire, particularly with fine ore, or crushed ore, in open heaps, has led to the construction of mounds for roasting. These are walled-in areas; a certain space of ground, say twelve feet by eight feet, is surrounded on three sides by a low wall, small chimneys being erected in the interior of the inclosed space; the walls are from two to three feet high, having fire-rooms in their lower parts near the ground, or even below it. Several such furnaces are generally built together under a shed, and two of their walls are therefore mutual. These mounds are particularly suited for roasting fine ores, and washed powdered ore, but the operation is tedious, and requires more attention than our smelters can pay to roasting. Moulds have been tried in this country for roasting, but are now generally abandoned.

On Furnaces.—Furnaces, or roast-ovens, are also used for roasting ores; they differ greatly in their construction, according to the method of their use. Iron ores are roasted in ovens similar to a common lime-kiln of large size, and one that may serve for either roasting or burning lime. No fine or small ore can be roasted advantageously in an oven of this kind. For other ores than carbonates of iron, (argilaceous ores,) these kilns are not well adapted. Pyrites cannot be roasted in them, neither most other ores, because it is impossible to regulate the heat so as to prevent the melting of the ore; and if this happens, of course that ore is either lost or is with difficulty recovered. In roasting poor iron ores it is extremely difficult to regulate the fire so that no parts of the ore are burned dead or melted. For these reasons, kilns for roasting are not so much in use as would naturally be expected; they save fuel, but are more expensive in labor than the open heap.

The Reverberatory Furnace.—This apparatus forms one of the best furnaces for roasting; but as its application is by no means general, and as the form of a roasting furnace is modified according to the kind, form, and uses of ore, we shall allude to this method when treating of those substances to which it is applied.

There is a variety of forms in the apparatuses for roasting, but we cannot perceive any advantage in the use of them; neither in the form of lime kilns, for wood; nor cupola furnaces, constructed like porcelain kilns; nor large chambers, into which the flame from a grate is conducted through the ore; nor other forms of apparatus. These contrivances are not calculated for our smeltworks; they cause more labor, and absorb more capital, than a smelting business can afford.

Principles of Roasting.—Roasting means to heat a substance, a metal, or a metallic ore, or matt, to at least a red heat, or such a heat that the mineral does not melt, but only the volatile or combustible substances are expelled, and at the same time as much oxygen becomes combined with the ore as it possibly can absorb. It is therefore a principal condition, that with the heat a liberal quantity of atmospheric air, or oxygen, is admitted. In some cases chlorine, carbonic acid, carbon, or steam, is required along with the air, or in their pure conditions. In most instances, the object is merely to oxidize the ore to a higher degree, or to drive off volatile matter and in the mean time oxidize the ore, or to combine chlorine with a certain metal, as silver; or to reduce ore to metal, and evaporate the latter, which is the case with arsenic, zinc and antimony.

The operation proceeds faster when the ore is fine than when it is coarse, because more surface is offered to the oxidizing agent; but this method includes the motion of the particles, so as to expose their various sides to the heat. It is not always necessary that the ore should be a fine powder; but it is of great advantage to have it in pieces of uniform size, because the action of heat and air is more regular, and the surfaces acted upon are larger. In roasting more or less fine powder, it should be stirred and moved while hot. The melting of the substance must by all means be prevented, for in that case neither evaporization nor oxidation can be accomplished. In the large operation, and in the reverberatory furnace, the melting of any kind of substance which is to be roasted is easily prevented. Roasting is always applied to oxidize iron ores, in order to obtain the highest degree of oxidation. A simple oxidation is performed when magnetic ores are exposed to heat and air and transformed into peroxide. Chlorides are produced when for instance hot silver ore is brought in contact with chlorine, or a salt of chlorine, such as common salt; the roasting operation is here performed to reduce the oxide. When arsenic is to be evaporated, we put carbon in the mixture, and produce metal, which is more easily evaporated than its oxide. An evaporating, roasting process, is that which is performed on hydrated oxides when only water is evaporated; a compound operation is performed when evaporation and oxidation are produced at the same time. In roasting pyrites, blende and arseniurets, the volatile substances are driven off by heat, and the remaining metal is at the same time oxidized, which is brought in most instances to the highest degree of oxidation.

The affinity of the metals for other substances than oxygen, and the form in which these combinations appear, modify the process of roasting considerably. We shall allude to these particulars in the proper places; but it may be proper to state here some general circumstances which have a bearing upon the subsequent operations. Iron cannot by any means be entirely freed from sulphur, phosphorus or arsenic, by roasting; the presence of the vapors of water facilitates the expulsion of these substances, but the roasted ore never can be made entirely free from them. Blende, or sulphuret of zinc, is extremely slow to oxidize, and never can be purified from all the sulphur. Sulphuret of bismuth is equally slow of oxidation, not for want of affinity for oxygen, but because it is so highly fusible that its melting cannot be prevented. Sulphuret of copper is easily purified from all its sulphur. Galena is of very difficult oxidation, almost as much so as bismuth. Sulphuret of silver is easily liberated from its sulphur, and forms metal; the same is true with gold. Mercury acts in a similar manner, but it requires some caution to avoid evaporating the sulphuret of mercury with the sulphur. Sulphuret of antimony is of difficult oxidation, because it is extremely fusible. Sulphuret of arsenic is easily decomposed, but the result of the oxidation evaporates; the arsenious as well as the sulphurous acid both evaporate. The sulphurets of nickel and of cobalt are easily oxidized, and form pure oxides. Phosphorus and arsenic act in a similar manner as sulphur, and what applies to the latter applies to the former, with slight modifications. Phosphoric acid is more permanent than sulphurous acid, and silver cannot be entirely freed from arsenic if once combined with that substance.

CHAPTER III.

Smelting.—When metallic ores are exposed to heat and such reagents as develope the metal, we call it smelting, in contradistinction from the mere application of heat, which causes ore to become fluid, and is called melting. Smelting is a chemical operation, conducted on the same principles as a moist assay in the laboratory; excepting that we produce in this case but one valuable substance, the metal, and consider the slags as accidental results. The slags require the closest attention of the metallurgist, because if they are of the right composition, the metal will invariably appear in the proper form. In all cases of smelting, it is an essential condition that the degree of heat should be so high as to cause all substances to become perfectly fluid. In principle there is no difference—if we mix two fluids, or a fluid and a solid, which show different affinities for the matter in solution—if the fluidity is produced by matter which is fluid at common temperatures, or only at a high heat. If oxide of iron is put into a watery solution of the sulphuret of potassium, the result is sulphuret of iron and potash; if the sulphuret of potassium is melted by heat, and we put into the fluid the oxide of iron, we have the same result; sulphuret of iron and potash are in the hot, melted mass. If some potash or soda is put into a red-hot solution of silicate of lead, metallic lead is precipitated, because the potash has more affinity for silex than oxide of lead. When into a fluid silicate of iron, carbon, lime, or other bases, or an oxide of metal is brought, such as manganese, which has more affinity for silex than iron—it will deprive the silex of its iron, and precipitate the latter in its metallic state. The manipulation in the laboratory differs from the manner of operation in metallurgy, but we recognize in both the same laws of affinity.

In almost all smelting operations, the object is to produce a certain metal, and to form of all the other metals oxides and slags. This operation is greatly facilitated by the fact that most of the metals are specifically heavier than their melted oxides, or than these oxides in combination with silex or other acids; and if slags and metal are actually rendered perfectly fluid, they will separate in consequence of their want of affinity and their difference in specific gravity. This case is like that of common fluids. Water and oil may be mixed, but soon they separate, the oil floating in a distinct stratum on the surface of the water. Metallic lead and oxide of lead, or a silicate of the oxide of lead, or any other silicate, may be mixed when in a rigid state, and they do not separate; but when both are fluid or melted, metal and slag soon separate, the former being found below the latter. When lead, iron, and slag are melted together, we obtain lead for the lowest stratum, iron on that, and the slag above the iron. The specific gravity of each indicates their relative positions. In all smelting operations we obtain at least two separate strata, often three, and in some instances four, of different substances.

Metals.—These are contained in the ores, in most cases, as compounds; and if it is the object to separate them we are to put such matter in contact with them as will deprive the metal of its compound. If a silicate of iron is melted, we do not precipitate iron by adding carbonate of soda or caustic lime to the fluid mass; this addition merely increases the fluidity of the slag without producing any metal. But if we add sodium, the oxide of iron will be deprived of its oxygen and form metal. Carbon has more affinity for oxygen than metal in the high heat of a melted silicate; if therefore we add carbon to the melted silicate of iron, some iron is produced in all cases. When in this instance sufficient iron is precipitated to deprive the slag of its fluidity, no metal is formed, however much carbon we may add; for the metal requires a slimy, glassy coating to protect it against the influence of oxygen. When exposed in small particles to the influence of oxygen, almost all metals burn more readily than carbon—gold, the platinum metals, and silver, in some measure excepted. If, therefore, we desire to obtain metal, we must produce a slag which protects it and at the same time admits of its coagulation. If to fluid silicate of iron, potash or soda is added, and at the same time carbon, metallic iron will be produced, because the slag retains its fusibility by this addition; but when so much iron is precipitated as to render the slag not sufficiently fusible to cover the metal with a slimy coating, the presence of potash even will not prevent the iron from burning. Carbon in any form has a strong affinity for oxygen, and precipitates all the metals from oxidized compounds; but it must never be forgotten that metal in fine particles has more affinity for oxygen than carbon, no matter how high or low the temperature may be. It is evident from this that no metallurgical operation can be perfect until the heat is sufficient to melt both metal and slag. Some metals are extremely refractory, and do not melt in any heat we can produce by means of carbon; such are platinum, chromium, iron, and others. In these cases, we combine the metal with other substances which cause it to be fusible. Platinum is fusible in combination with lead; chromium in combination with arsenic; and iron in connection with carbon, phosphorus, arsenic, sulphur, and a number of alloys, is fusible, while by itself it cannot be melted. By these means we may precipitate and melt a metal, which without such an addition would not melt. Silver and gold, if pure, do not melt very readily, and they evaporate at a heat only little higher than their melting point; it is therefore necessary to combine these metals with one that is more fluid, in order not to lose much of them. These considerations will lead the metallurgist to employ the proper means for obtaining the metal in a fluid state.

Slags.—As was remarked above, the composition of the slags determines the quality and quantity of the metal produced; and if considerations of economy did not interfere with the application of fluxes, other than natural ones, there would be no limit to the production of metals in quality and quantity. Slags are glasses compounded of substances which melt at a particular degree of heat for each definite composition. The study of the nature of slags forms the science of smelting; the metals follow of course when the fluxes are correctly compounded. It is not always the case that metals are obtained at first melting; some ores are first converted into matt, such as copper, then roasted, and the metal extracted by a series of roastings and smeltings. These operations, all made with a view of compounding a proper slag, complicate the smelting process so far that we distinguish in them oxidizing, melting, reducing or smelting, and refining. Each of these operations involves different principles, and we shall for these reasons speak of them before treating of the composition of slags.

Oxidation.—When sulphurets which cannot easily be desulphureted by roasting, such as copper pyrites, are to be smelted, we either melt and roast by atmospheric air, or by the addition of oxides to the melted mass. When iron pyrites is melted together with the oxide of iron, a large portion of sulphur is evaporated in the form of sulphurous acid, and the remaining sulphuret of iron when exposed to the atmosphere is easily decomposed; part of it is converted into green vitriol, and the rest forms peroxide of iron.

The oxidizing operation is facilitated either with or without the assistance of atmospheric air, by all the highest oxides of metals, such as oxide of lead, peroxide of iron, black manganese, saltpetre, common salt, silex, water, and in fact any substance which gives off oxygen, or facilitates an absorption of atmospheric oxygen. Oxidizing smeltings are often far cheaper than roasting, and it is an object which well deserves the attention of the metallurgists of this country; it requires less labor and fuel to oxidize sulphurets in this manner, than by roasting, pounding, and washing. In the large operation we cannot employ litharge or saltpetre as a means of oxidation, because they are too expensive but instead of them; we use coarse silex, gypsum, salt, oxide of iron, or black manganese. In this case, it is all-sufficient to mix the mineral with such substances as cause it to divide and offer more surface to the atmospheric air. The substances used for oxidation are dependent entirely on the quality of ore and the mode of operation in the subsequent reducing process. If we roast galena with fine silex, which of course will soon liberate the lead from sulphur, not much metal can be obtained, because the slag formed by the oxide of lead and silex is so far infusible as to admit of no separation of the lead from it. But if the silex is used in large grains, which leaves sufficient spaces for the globule of melted metal, we may obtain as much metal in the presence of an excess of silicious matter, as in a perfectly fluid and alkaline slag. This of course excludes the possibility of a fusible slag, but it serves as an illustration of the principles involved in smelting. Any other substance than silex may serve the same purpose, provided it has no affinity for that which is to be removed by evaporation, and is sufficiently refractory to resist melting with the oxide produced by that metal which is to be oxidized. The most extensive application of oxidizing melting is made in smelting sulphurets of copper in reverberatory furnaces. In this case iron must be always present; this metal combines with sulphur more readily than copper, but it also parts with it more readily, when exposed to the effect of the oxygen of the atmosphere; the oxides of iron thus formed absorb sulphur from copper as long as any is present; and when all the sulphur is expended the iron forces the copper from its combinations with silex. Common salt is profitably employed for oxidation; all chlorides are volatile, and so is common salt; but if the quantity used is small, and it serves as a mere assistant in the operation, it will long resist the influence of heat, particularly in alkaline slags. In the presence of clay or lime, common salt will bear a high heat for many hours without scarcely evaporating. Salt to the amount of one or two per cent. in the slag, will resist the heat of a puddling-furnace for 24 hours, without being expelled. Sulphates act like chlorides, but it is necessary that no carbon should be present; the latter will decompose any sulphate in a melted condition, and it ceases then to act as an oxidizing agent. The presence of carbon facilitates the evaporation of chlorides also, but that which remains is still a powerful means of oxidation.

The oxidizing operation by smelting is always imperfect, that is, all the volatile substances, such as sulphur, arsenic, antimony, and phosphorus, are never removed entirely, and the metal is obtained gradually. The presence of the volatile matter serves in part to liquefy the slags. By these means, copper, lead, antimony and a few other metals may be obtained; but when it is an object to produce all the gold and silver contained in an ore, every particle of sulphur, &c., should be removed, and the mineral brought to the highest state of oxidation, before subjecting it to the reducing operation with carbon.

Reducing.—The means employed for obtaining metals from oxides, and other compounds, are so extensive and varied, and the apparatus so well adapted for accomplishing the object in view, that speculations on this subject are the most interesting of all branches of industry to which intellect may be applied. As remarked before, this is a simple operation. Conducted on the principles developed by chemistry, the mineral may require water for solution or heat; but as the composition of minerals is extremely variable, the means employed are of course equally so. The heat ranges from the boiling point of water to the highest attainable. The means of reduction are, metals, and to some extent the oxides of the heavy metals, alkalies and alkaline earths, carbon, hydrogen, carburetted hydrogen, and a variety of other matter.

By Metals.—If we put into a fluid solution of sulphurets, arseniurets, or oxides, a metal which has more affinity for sulphur, oxygen, arsenic, &c., than one of the metals in solution, the latter is precipitated, and the first assumes its position in the fluid mass, provided it is soluble. If it is not soluble it will still absorb the substance for which it has most affinity from the metal, and float upon the reduced metal, provided the latter is heavier and both have little affinity for each other. This operation must be conducted with all the niceties of a chemical experiment. When sulphuret of lead or antimony is melted, and pure metallic iron is placed in contact with it, the iron will absorb the sulphur from these metals and produce them in their pure condition. Lead has little or no affinity for iron, the metal produced is therefore pure. Antimony combines readily with iron, and if the quantity of the latter is larger than merely to absorb the sulphur, it will combine with iron and form an alloy. In the first case it does no harm if more iron is used than is required, but in the latter it is injurious to the metal which is to be reduced. The quantity of the substance used for liberating metal from its combinations is here of equal importance as in chemistry, and the same laws are applied; the quantity increases the affinity. When a large quantity of iron is present in copper ores, we may succeed in obtaining almost all the copper; but when little iron is in the slag, the copper has such affinity for either volatile matter or silex, that a large per centage remains in the slags, which can be recovered only by heavy expense. In all operations of this kind, we are, therefore, to consider the affinities and also the amount of the mass.

By Oxides.—When a mixture of potash and soda is melted, and we add to it a sulphuret of a metal, whose basis melts below the heat of the alkaline sulphuret, and whose sulphuret is not soluble in the alkali, we obtain a certain portion of the metal, and often the whole of it. Zinc blende, galena, and the sulphurets of the fusible metals, form pure metals which separate; but iron or copper pyrites form no metal, because they do not melt in that heat, and remain either as oxides or sulphurets in the solution. Sulphurets of gold, platinum, or silver, do not produce metals, but when lead is present a part of these metals may be obtained. The sulphurets of arsenic and tin do not form metals, because these combinations as well as their oxides are soluble in alkalies. The same law which is here applied to potash and soda, is applicable to the alkaline earths, and metallic oxides when these form fluid slags. Lime will effectually reduce the sulphuret of any metal, but as the heat by which it melts is very high, we can produce only those metals which do not evaporate at that heat. If the vapors of the metal are equally valuable with the melted metal, such as quicksilver and zinc, we reduce sulphurets by the use of lime successfully. When lime is used to excess in reducing sulphuret of iron, the latter may be freed from sulphur almost entirely. In the same manner, protoxide or magnetic oxide of iron acts upon galena; if the iron predominates and becomes fluid at so low a heat as not to evaporate the lead, all the lead may be obtained. The application of these principles is extremely important in metallurgy, and it deserves more attention than is commonly paid to it. Oxides of metals cannot be reduced by other oxides, unless the higher oxidization of a newly formed oxide is more soluble than the previous one. When oxide of lead or of tin is cast into an alkaline silicate of iron, some metal is produced; this is not because the higher oxidization of iron causes the slag to be more fluid, but because some of the iron may be more highly oxidized without interfering with the fluidity of the cinder; the addition of some oxide of lead which remains, causes it to be more fluid, or at least retain its fluidity.

Carbon.—Of all the means at the disposal of the metallurgist, carbon is the most available for reduction. It is of little use in reducing chlorides, sulphurets, and arseniurets—for these metals are necessary; but as most minerals are in the form of oxides, and carbon is, in the high heat required, a strong agent in removing oxygen, it is generally applied. Hydrogen is also an effective means of reduction; but as its compound, water, oxidizes hot metal readily, and as the heat by which it operates is generally too low to melt the metal, its application is extremely limited. Hydrogen is employed in some cases, in its combinations with carbon, to reduce oxides, such as oxide of tin, or zinc; but it is then used to a very limited extent, such as the small quantity which is present in the coal employed, whether bituminous mineral coal or soft charcoal. This gas has in many cases a decided influence on the smelting operation, as we shall see; and it is mostly removed by charring that fuel which contains hydrogen to an injurious extent. Carbon is particularly suitable for the reduction of oxides in consequence of its volatile compounds with oxygen, and its harmless combinations with the metal produced. The results of the deoxidizing operation, that is, carbonic acid and carbonic oxide, are extremely volatile, and escape without any injury to the slags, or the metal produced. When carbon is brought in contact with oxidized ore, and there is no other oxygen present but that in the ore, it will be forced to combine with that. When a mixture of carbon and ore is exposed to fire, no combination between the ore and carbon can ensue, because both are rigid and the particles cannot move; and as motion is indispensable in any chemical operation, no combination between carbon and the oxygen of the ore could happen, unless one or the other was made fluid by heat. In the first place, there is always some air, particularly oxygen, in the pores of charred coal—also in the pores of ore; this oxygen is at liberty to move and will combine with carbon, and as carbon is sufficiently abundant the combination formed is carbonic oxide. This gas will combine with another portion of oxygen where it finds such at a sufficiently high heat; and inasmuch as the ore nearest to it is hot, the gas will absorb oxygen from the ore and escape in the form of carbonic acid. The ore thus deprived of oxygen produces metal. This explanation may serve in all those cases where the metals readily part with their oxygen, but it is not sufficient to explain the reduction of metals which have a strong affinity for oxygen and even melt with their oxides. For these reasons the refractory metals are smelted with fluxes, which cause the ores to become fluid, and in this manner they are brought in close contact with the coal. The use of fluxes is, therefore, not confined to the absorption of foreign matter; it is highly valuable in accelerating the smelting operation. For this reason we see the oxides of lead, bismuth, antimony, nickel, and cobalt, reduced very readily; because the oxides themselves, or mixed with fluxes, form fusible slags which readily flow over the carbon and cause a close contact between it and the oxygen. Tin, zinc, iron, chromium, and manganese, are not easily reduced, because their oxides are very refractory, and the first two metals evaporate in that heat at which carbonic acid is formed from their oxides; for these reasons it is necessary that soft charcoal or bituminous coal be used in their reduction. Neither the oxides of the other metals, nor the metals themselves, melt readily; but if we cause the oxides to become more fusible by adding fluxes, and the metals by alloying them with a substance which makes them fusible, we may produce either of these metals very readily. The reduction in most cases takes place previous to melting—and it is in fact not necessary that the ore should be melted before reduction ensues; but if it should be, it facilitates the formation of metal.

The doctrine that carbonic oxide is the agent in the process of reduction is not objectionable, so far as those metals are concerned which are not oxidized by carbonic acid, and which do not absorb carbon. This theory does not, therefore, apply generally. Some metals decompose carbonic acid—they cannot be reduced by it or in its presence; others again absorb carbon, which neither carbonic acid nor the carbonic oxide can afford; and it is necessary to adopt a hypothetical compound of carbon and oxygen in order to explain the carbonized state of some metals, such as iron, lead, manganese and others. The combination of carbon and metals appears to be in most cases a mere mechanical mixture, and it cannot be assumed that the affinity of metals for carbon is so strong as to decompose carbonic oxide. We shall illustrate this subject by referring to a particular case in which carbon is of peculiar effect, namely, that of iron. When iron ore is smelted in a blast-furnace, it is found not only difficult, but almost impossible to manufacture gray iron from magnetic ore, when not roasted or oxidized previous to smelting. It is impossible to make gray iron by smelting silicates of any kind, such as forge cinders or puddling-furnace slag. If only the presence of carbonic oxide was required, these forms of iron ore ought to furnish gray iron as well as any other ore, for the ore is constantly in contact with that gas and with pure carbon also. We explain this by referring to the compact form of the ore. All the ores which are compact are reduced by the carbon acting on the exterior particles of the lumps. The metal formed being fluid, runs off by accumulating into a body, which is in that form not accessible to carbon, or capable of forming any compound with other matter, because the points of attraction and contact are wanting. No matter, however, what the rationale of this phenomenon may be, the fact is generally known. Porous iron ores—spongy hydrates—are the most suitable to produce gray iron—in fact, they produce it as a necessary consequence of their form. If the latter was not the cause, this ore would be as little suited to form gray iron as any other, for it is of the same composition as specular ore, containing generally, however, more impurities than the latter; still it is very difficult to make gray iron of specular ore, and in fact of every kind of compact ore, no matter what may be its composition. Compact ore may be either perfectly pure, or very impure; neither condition renders it suitable to form gray iron. If iron, or its compounds, are in a porous condition, there is not the slightest difficulty in combining them with carbon. We conclude, therefore, that carbon penetrates into the pores of ore and metal in a solid form; for it is evident that spaces are required to bring particles of carbon in contact with particles of ore, or the compact ores would form gray iron quite as well as porous ores.

If porosity of the ore or metal is an essential condition of carbonizing it, then it is evident that carbonic oxide gas cannot have the power of conveying solid carbon to the metal, for that gas will penetrate less porous bodies than iron ores of a compact form. When carbonic-oxide gas is the agent, it will carbonize iron wherever it finds it in a proper condition; for if it is fluid, all the requisites of combination are presented. Still, we know by experience that pure carbonic oxide will not carbonize iron in the converting box of the steel manufacturer; it requires the immediate contact of solid carbon and solid iron to form a carburet. Iron may be carbonized and decarbonized when in a fluid state, but the operation is extremely slow, and cannot be supposed to happen in a blast-furnace where the melted metal sinks down into the hearth rapidly. We assume, therefore, which assumption is supported by experiment, that carbon in a solid form is deposited in the pores of the ore before it is melted, and that in melting the cohesion of the metal brings the carbon into so close contact with the metal as to force it into its pores and effect a union. The carbonizing of iron in the converting box presents no objection to this theory, as we shall see hereafter.

When carbon is present in the ore before it is melted, how does it get there? how is it deposited in that form? Carbonic oxide cannot deposit carbon, for it finds abundance of oxygen in the ore to combine with, and will naturally form carbonic acid. But supposing carbonic oxide was decomposed in the pores of the ore, the result must be carbonic acid in all cases, which is evidently not the fact in the blast-furnace, for we find the latter filled with carbonic oxide nearly to its top; at least so far down as any carbonic acid is formed no perceptible alteration is observed in the ore. From the lowest point where carbonic acid ceases, downwards, the effect of carbon commences, the cementation of ore goes on, and still there is little or no carbonic acid gas in the furnace. A cold plate is blackened when held over the flame of a clear burning candle; solid carbon is deposited from the gaseous solution of the flame. It may be objected to this parallel example, that in the flame of oil and of fat there is an abundance of hydrogen, which holds carbon in solution. May not carbonic oxide have a similar effect on carbon as hydrogen when at a high heat? The solvent power of this gas for carbon may be very faint, existing only at a high heat, and being destroyed at a diminution of that heat. The operations of the blast-furnace, the mode in which the blast is introduced, and the appearance of the ore and gas in the furnace, confirm this theory of carbonizing iron. We shall, in subsequent pages, allude to this subject again.

Alloys.—If we adopt the foregoing theory for combining carbon with metals, we obtain at once a clear, comprehensive view of the conditions under which alloys, and the various combinations of metals and other substances, may be formed; and as these combinations are of the utmost importance to the metallurgist, they are well worth the trouble of a close examination. It is not only the combination, but also the separation of such combinations, which are of interest. The above demonstration shows at once under what conditions alloys may be formed, even if the affinities and other relations are averse to any combination. We may melt pure iron and arsenic metal together as long as we please, no union of the two can be effected; the arsenic evaporates before the iron is sufficiently hot for its combination. But if we heat fine iron filings and arsenious acid with carbon, at first gently, we may melt both together very readily and obtain an extremely fusible arseniuret of iron. This operation is still more easily performed if we heat borings of gray cast-iron and arsenious acid together. And this alloy may be produced in any form or compound which we choose, if we mix arsenious acid, oxide of iron, and carbon in grains together, and bring the various particles in close contact before heating, by moistening the mixture with a weak solution of potash or soda, and drying the whole before smelting. A very slight heat will melt this alloy, and all the iron in the mixture is readily obtained under a cover of carbon. The most refractory metals may thus be made fusible, and obtained from their ores, and the facility with which they are produced depends on the arrangement which we have made before smelting is commenced. Chromium is very refractory, but if we mix its oxide with carbon and a little phosphoric acid, and moisten the mixture with an alkaline solution, so as to bring all the ingredients into close contact before smelting, we obtain chromium at a low heat in a perfect button, which is of course adulterated by phosphorus. It is extremely tedious to reduce potash so as to obtain potassium in a pure form, but there is not the slightest difficulty in combining antimony with potassium to a large extent; and if it was an object to produce potassium on a large scale, some means may be devised to separate the two metals. These relations show distinctly by what means and modes combinations of metals and other substances, or metals among themselves, may be effected. If we had it in our power to form perfectly pure oxide of iron, and mix it with perfectly pure carbon, and exclude any other matter, such as silex, from coming in contact with the mixture, steel might thus be formed to perfection. But, as one of the first conditions in thus producing steel is the absence of all other matter except pure carbon and pure oxide of iron, we may reasonably doubt the possibility of producing good steel by these means, because on a large scale neither oxide of iron nor carbon can be obtained sufficiently pure. It is therefore necessary to produce metallic iron in that form in which it has the least impurities,—that is, pure wrought-iron,—and cement it in such a manner that other substances than those which are volatile cannot come in contact so as to penetrate its mass. When iron melts by excess of heat in the converting box, it is changed into impure cast-iron, of which steel cannot be made; in this fluid state it absorbs so much silex from the charcoal as to form a brittle compound.

When metals are in intimate connection with other matter, they are in the best state to form new compounds. When an alloy is melted and mixed with another alloy, or a compound, the particles will combine according to their predisposition; elective affinity is quite as active here as in any chemical process performed under different circumstances. When melted galena is passed over red-hot pure iron, metallic lead and sulphuret of iron is produced; and when fluid carburet of iron (gray cast-iron) is poured into fluid litharge, iron and metallic lead are produced. When an alloy of lead and tin is mixed with melted iron, the latter will combine with the tin and separate the lead. Gray cast-iron, mixed with a silicate of iron, will reduce so much of the oxide of iron as its carbon indicates; this operation is often accidentally performed in the puddling-furnace of the iron works.

From these speculations it is easy to infer the great importance of the composition of the slags for the purity of the metals produced. In all smelting operations, slags must be formed in order to remove the impurities of the ore; and when carbon or any other substance is combined with the metal produced, and that may be retained in the cinder when the metal passes through it, in most cases the carbon, &c., will change places with some substance in the slag. The metal is thus adulterated with the substance taken from the slag. This subject is of extreme importance, and we shall refer to it whenever occasion demands.

Separation by Weight.—In reducing metals from their ores, it must be the aim of the operator to form globules and at the same time form such spaces, through which they may descend. In a mixture of ore and carbon, if the latter is so fine as to prevent the descent of the metal, this may be perfectly reduced, and still no accumulation ensues; this happens particularly when an excess of carbon is used, and as this is inevitable in large operations, it is advantageous to select the coals in coarse parts. The larger these globules, the size of which is facilitated by coarse carbon, the faster their descent will be. When small globules reach a mass of fluid slag, and are too small to penetrate it, they will remain on its surface, and even may be suspended within the body of it. This phenomenon happens frequently at blast-furnaces;—it may be, at those for smelting lead, copper or iron; a stiff slag will always retain metal in round grains, which is often found to amount to a considerable portion of all which is produced. If the slags are thrown away, this metal is entirely lost; but it may be recovered by pounding and washing the slags. At iron furnaces this loss amounts in an average to five per cent., often more; it is considerable at copper and lead furnaces, and in fact cannot be avoided in any smelting operation. The larger the globules of metal, the less are they liable to be retained by the slag. It is therefore disadvantageous to use too small coal, or form a stiff, tenacious slag.

Slags.—The form of slags, their fluidity and composition, is of so much importance to the metallurgist, that too much attention cannot be paid to this subject. In previous pages we have alluded to it, so far as assays are concerned, and shall confine our remarks here to operations on a large scale. The substances of which slags are formed are chiefly, silex, as the acid, and the metallic oxides as bases or alkalies. Besides silex, we find, however, carbonic acid, chlorine, sulphuric acid, fluorine, phosphoric acid, and others in the slags; also sulphur and phosphorus. The alkalies are chiefly, oxide of iron, the oxides of manganese, lead, and copper; the alkaline earths are clay, and such fixed alkalies as are brought into the mixture accidentally, either by the ore or by the fuel. The substances which are added to an ore, in order to separate the metal, are fluxes, of which the number is very limited, because considerations of economy compel the smelter to confine his selections to a small number of minerals and artificial ingredients. The most common fluxes in use are limestone, oxides of iron, and iron pyrites; silicious or ferruginous slates and shales; clay; fluor spar; black manganese; common salt; and a few other substances.

Fusibility of Slags.—The degree of heat at which slags melt is very different for different compositions, and ranges, as remarked before, between the boiling point of water and the highest attainable heat. When it is the object to liquify silex, the only agents by which to do it effectually are potash, soda, lime, oxide of lead, oxide of iron, and manganese. The presence of phosphoric acid or chlorine will not add to the capacity of these substances for dissolving silex, but as their combinations with metals are very fusible, they increase the fluidity of the slag; this alludes particularly to those slags which contain an abundance of metallic oxides. It cannot, therefore, be the object to dissolve silex by any such acid, but to cause the bases to be more fluid, and by that means compel the imperfectly dissolved silex to float more freely in the slags. The application of other acids than silex is limited to low heats only, because they generally evaporate before certain combinations or reductions can be effected. Protoxide of iron is the substance most generally used for dissolving silex, not because of its fusibility, but because it can be obtained abundantly in every place, its cheapness being the cause of its general use. Lime is next in importance to oxide of iron as a flux, but it does not form quite as fusible a slag with silex as iron or manganese; and metals which cannot bear a high heat, cannot be fluxed by means of lime, magnesia, clay, and similar substances. The fusibility of sulphurets is in many instances resorted to as a means to form slags, but these cannot dissolve silex, and so far as the latter substance is removed by sulphurets, it is only by its being suspended in the fluid mass and rendered more fluid. Yet, all these heterogeneous substances may be united in a slag and form a perfectly fluid mass;

and it is an important fact to be known in metallurgical operations, that all compounds are more fusible than single elements, and all slags increase in fusibility as their number of elements increase. This relates to metals and alloys as well as to slags; and on this principle all operations must be conducted.

Lime and silex are not very easily melted; clay and silex show hardly any signs of melting; but lime, clay and silex melt very readily together. Protoxide of iron and silex form a fusible slag, but when manganese, or lime, or soda, or potash is added, the fusibility of the slag is remarkably augmented. In all cases, the fusibility of a compound of various slags is greater than the mean fusibility of the whole, when considered as melted by themselves. If a compound of lime and silex melts at 3000°, that of protoxide of iron and silex at 2000°, and that of a silicate of oxide of lead at 1000°, the mean heat of the three, by which they will melt when mixed together, is not $\frac{3000+2000+1000}{3} = 2000°$, as their various degrees indicate, but it may be only 1500°, and in this case even lower than that. The greater the number of elements in a slag, the more fusible it becomes; it is, therefore, of the utmost importance in all smelting operations to multiply the kind of ores; this produces fusible slags and fusible metals. In smelting iron, copper, lead, and all other metals, these rules are very well known by experienced smelters, and attended to; still they are not so much observed at the furnaces as they should be. As foreign matter has a decided influence upon some metals, it requires extreme caution in the selection of fluxes for certain kinds of metal. A flux which contains phosphorus will not in the least interfere with the quality of lead, but does great harm to iron, less to copper, and none at all to silver or gold. The presence of arsenic in an iron ore causes cast-iron to be very short and hard, but it has a beneficial influence in making wrought-iron; this substance cannot be removed from silver but by a tedious refining process; it acts in the same manner with lead. Sulphur is very injurious to iron and copper, but has no effect whatever on lead; silver and gold are more or less affected by its presence. The selection of fluxes must be, therefore, made with some discrimination and judgment in these respects.

Slags should be as fusible as the metal which is to be smelted with their assistance. If they are more refractory than the metal, the slag causes it to assume a heat by which more or less of it is evaporated. The slags must be so compounded that the flux which is added to the ore has more affinity for the foreign matter than for the oxide of the metal, or the metal itself, which is to be produced. In the mean time the new compound formed by the flux and the foreign matter ought to be more fusible than the metal, so as to float down before the metal is perfectly melted. In some instances, namely, in those where the metal is to be carbonized, this rule is not applicable, for it invariably removes the carbon from the metal. By means of such a fluid slag any kind of impurities may be removed from the metal when properly attended to. Another advantage of a fusible slag is the saving of fuel, for in this instance there is no need of raising the heat beyond the melting point of the metal.

Learned men have demonstrated that certain quantities of particular matter are required to form the most fusible compound. There is no doubt that certain laws regulate the formation of slags, which have evidently a strong bearing upon the results of metallurgical operations, but in smelting we cannot pretend to the niceties of the laboratory, and it is quite sufficient if we approach the laws strictly regulating this subject. When a slag is tough and tenacious it requires an alkali to make it more fluid; and if it is hard and brittle, inclined to chill, it requires an acid to flux it. In many cases the addition of other slags, so as to increase the quantity, causes the slag to be more fusible, and affords at the same time a protection to the metal. We shall speak more particularly on this subject in the various places on smelting metals, but will here allude to a few facts which indicate the importance of composition.

A slag taken from a blast furnace for smelting iron, and which was composed of 50 silex, 17 alumina, 30 lime, and 3 protoxide of iron, melted by 2576°; but when the ingredients forming this slag were put together, finely powdered and mixed, and then exposed to heat, it required 3400° to form a slag of them. This shows how much more heat is required to melt a crude mixture, than to melt a compound in which the particles are already arranged. It shows at the same time, that when the flux or a part of the flux is soluble in water, it ought to be dissolved so as to bring it and the ore in close contact before exposing them to the influence of heat. Another composition of iron slags, which consisted of 58 silex, 6 clay, 2 protoxide of iron, 2 protoxide of manganese, 10 magnesia, and 22 lime, required the same heat as above for softening it, namely, 3400°. The heat by which it was kept in fusion was also similar to the above, namely, 2600°. Slag from a lead furnace, which was held in a fluid condition by a heat of 2400°, required 2650° for softening the ingredients of its composition. That slag was composed of 36·5 silex, 40·5 protoxide of iron, 8·5 alumina, 4· lime, 3· magnesia, 7·5 oxide of lead. A slag from a copper smelting furnace, for crude copper, contained 32·7 silex, 60·3 protoxide of iron, 7 alumina; this was held in a fluid state by 2400°, and required 2700° for melting the ingredients of which it was composed. We see here that the smaller the number of elements, the less readily a mixture melts.

In order to compare the above degrees of heat by which the slags are melted and kept in solution, with the degrees of heat by which metals melt, we annex the following: gold melts by 2000°, silver by 1870°, lead 630°, cast iron 2500° to 3000°, and platina 4580°.

General Reflections on Smelting.—In order to obtain a clear insight into smelting operations, it is necessary to analyze each process, and each part of that process and observe what influence certain causes produce upon the metal. Here, as every where, it is difficult to reason from effect to cause, and therefore we follow the other way of arriving at conclusions. And if we apply the well-known laws of chemistry, with due regard to temperature, we will hardly ever fail of coming to correct conclusions in our experiments. Of the metals, copper has the strongest affinity for sulphur; then follow iron, tin, zinc, lead, silver, antimony, arsenic. As shown here, copper has a stronger affinity for sulphur than iron, and still copper is desulphuretted by iron, simply because of the mass of iron present; if the latter does not predominate, sulphur cannot be removed from copper by iron. This is no exception to the law for disengaging sulphur, for it is very well known that affinity is increased by mass. The alkaline earths and fixed alkalies have still more affinity for sulphur than these metals; and still they cannot remove the sulphur from most of these metals. Sulphurets of zinc, copper, or iron, cannot be decomposed by melted potash, at least no metal is produced to any extent; galena may be reduced entirely by it. The reason is, that metallic lead is more fusible than its sulphuret, and will separate at a lower heat then will melt the latter in potash. Sulphuret of copper, or iron, does not dissolve in potash. The latter absorbs some of the sulphur, but still leaves the metals with so much remaining as not to form pure metal. If the copper or iron were more fusible than the sulphuret suspended in the potash, it would coagulate, form globules, and separate in the metallic state. Some metals are not formed of sulphurets, even if an abundance of alkali is present, until carbon is brought in contact with them. Of this kind are lead, copper, and some others. Lime forms sulphates of lead, and lime of galena, and only a small portion of metal is separated; but if carbon is added sufficient to decompose these sulphates, nearly all the metal may be obtained from its sulphuret. In some instances the fusibility of two united substances is resorted to in order to dissolve the one. Sulphurets are not soluble in chlorides, neither are silicates, phosphates, or borates, and still a silicate with some chloride is extremely fluid; a sulphuret may be perfectly mixed with chloride in the heat of a grate fire; but as soon as the mass is cooled and water poured on, both separate. The cause is here obvious: sulphurets and chlorides, are both soluble in heat, but not in water, in which only the latter is dissolved; and as no affinity exists between the two, both separate very readily. Still this compound performs in it smelted condition all the services of a slag. Carbonate of soda is no solvent for any sulphuret; it will melt, and the sulphuret will melt; both may be mixed together, but no decomposition ensues; but if carbon is introduced, so as to decompose the carbonic acid, and liberate the caustic soda, it will absorb sulphur and produce metal, in many cases provided the metal is fusible in the heat which is applied. Copper may be reduced by these means. Iron cannot be melted, at least but very imperfectly, under a cover of potash or soda, because these substances will evaporate before the metal is melted. If carbon or sulphur is present in the iron, we may succeed somewhat better, but still imperfectly. If, however, a posphate is present, either in the iron or in the flux, and also carbon sufficient to reduce the phosphate, iron may be melted easily under a cover of potash or soda. The metal of course, which is the result of this operation, is very brittle, and a phosphuret, but it is chiefly iron. There is not the slightest difficulty in removing any quantity of impurities from a metal, by means of matter which has more affinity for these substances than the metal itself. This implies always the condition that the metal should be fusible at the same degree of heat, or nearly, at which the slag is fusible; also that it should not evaporate by that heat.

Sublimation.—Metals which are very volatile cannot be advantageously smelted; they are distilled, and in some cases sublimation is resorted to. There is not the slightest difficulty in smelting zinc, under a cover of carbonate of soda and potash, with carbon. But such a flux is expensive; and when not closely attended to while fluid, the loss is greater than the value of the metal obtained. It is for these reasons found to be cheaper to mix the oxide or carbonate of zinc with carbon, and distil it; or to mix the zinc blende with iron, and perform the same operation. The heat applied in these processes is by far higher than it is in smelting, and may cause the use of ten times as much fuel; still, it is asserted that distillation is cheaper than smelting. Mercury is frequently produced by simple sublimation, without the addition of flux or coal; so also is arsenic. But in most instances, carbon and such substances as decompose the ore, are added to it.

Refining.—The methods of refining metals are so various that a full description of them must be postponed to the third part of the work: a mere allusion to the subject is here sufficient. Refining gold and silver is done in large or small reverberatory furnaces, of which the bottom forms a cupel. Copper or lead is refined in reverberatories by melting, and the addition of fluxes. Tin is purified in reverberatory furnaces, and also in iron pots, being stirred by wood so as to oxidize its impurities. Zinc is refined in the same manner and by the same means. Iron is refined in charcoal forges, in run-out fires, in reverberatories, and in puddling and reheating furnaces.

Liquefaction.—This is a delicate operation, but it is of great utility. Bismuth is obtained by liquefaction. If the ore of this metal is heated with proper fluxes and in a proper apparatus to a degree of heat which will melt the bismuth only, it will flow out from the ore, and form metal without the rocky and foreign matter being converted into a fusible slag. Antimony may be obtained by the same means, and in fact every kind of metal, provided the remains of the ore do not melt partially so as to inclose grains of metal in a refractory, pasty cinder. As a mode of refining, it is chiefly used in separating silver from copper. When 11 parts of lead are melted with 3 parts of argentiferous copper, and this alloy is cooled slowly, the lead and silver may be made to flow out from the copper and lead; and the fluid lead thus obtained contains all the silver. The mode of operation in this case is generally to melt lead and copper perfectly, then cool it slowly. The copper and lead alloy, being the most refractory of the compound, will crystallize first, and the silver and lead last. When this combination of lead and silver, and the combination of lead and copper, is heated in a proper apparatus, the first will flow out at a certain heat and leave the other, which remains as a skeleton of the form of the whole body of alloy. Impure tin is refined on the same principle; when a pig of tin is laid on the highest part of the sloping hearth of a reverberatory furnace, and gently heated, the pure tin flows out first, and leaves behind a skeleton of iron, copper, and other metals, which do not melt at a low heat, and which are removed. This principle may be applied for the separation of metals by filtration; when, for instance, alloy is brought upon a body of sand, bone-ashes, lime, or similar matter, and melted, the moist fluid of the metals in the alloy will flow out first, pass through the sand, and a skeleton of the refractory metals will remain.

Crystallization.—Most of the metals crystallize readily; all of them crystallize by proper treatment. Antimony and iron are particularly distinguished for their power of crystallization. The alloys of metals are not so much inclined to form regular bodies, at least not at the same degree of heat; for these reasons alloys may be separated from the pure metal. The fluid metals act here on the same principle as a salt dissolved in water. This property of metals and alloys has led to a refining process for silver, which deserves more than passing attention in our country. When argentiferous lead is melted and then slowly cooled, the pure lead will sooner crystallize than the alloy of silver and lead, and a part of the pure lead may be gradually removed by a skimmer, or drainer. No perfect separation ensues here, for the coagulated lead still contains silver, and the richer the alloy the more silver is contained in the crystallized lead. Still, metal which contains but 10 ounces of silver in a ton of lead, may be concentrated with little expense, to lead of 30 ounces of silver per ton. When these principles are intelligently applied, much may be expected of them in the way of refining metals.

CHAPTER IV.

Fire-proof Material.—The apparatus in which smelting or melting operations are performed, is constructed of such materials as will not be seriously affected either by the heat applied, or by the chemical action of the minerals or metals. Besides these conditions, economy is generally considered; but we find, in most instances, that the saving of first expense should be a secondary consideration where fire-proof material is in question. The materials used as fire-proof, are sandstone, clay slate, shale, talcose slate, mica slate, granite, gneiss, porphyry, trap, and others, all of which are found native. Most of the fire-proof material used is clay, or aluminous sand, kaolin, and clay slate, which are formed into bricks, slabs, or blocks, so as to suit particular purposes. The artificial fire-proof stone, or brick, does not generally resist the chemical action of the metallic oxides so well as native material; it is therefore necessary to use compact native rock, where the action of metallic oxides is to be resisted. Bricks, when well made and of good material, withstand the influence of heat very well; and in all cases where sudden changes of heat are expected, fire-brick must be used in preference to any other material.

Materials which are considered fire-proof must be of such a nature as to resist the effect of heat, that of the metallic oxides, and the reducing influence of carbon also. Peroxide of iron is proof against heat, against most metallic oxides, and also resists silex very well, but it does not resist carbon; when the latter substance is present, or even its compound gases, peroxide of iron is reduced to protoxide, and forms now a strong alkali for any silex or acid which may happen to come within its reach. Silex, clay, magnesia, lime, and baryta, are substances which are melted only by a very high heat, about 4000°, which is not required in any smelting operation. It is therefore sufficient if the fire-proof stones consist chiefly of one of these elements. Their combinations melt more readily than each by itself; but it is sufficient when the main body, the bulk of the stone, is formed of one of them.

Native Fire-proof Material.—Quite a number of rocks, slate, and shale, serve the purpose of refractory stones. Some of these are so perfect as not to require more labor than quarrying and dressing; others must be broken, and cemented again in order to answer the purpose. As the refractory character of stones depends chiefly on the fusibility of their elements, we select them in most cases simply with reference to this quality; and as alumina, silex, magnesia, or lime, are fusible only at a degree of heat which is not often required in smelting operations, it appears to be all-sufficient, in order to secure durability, to select the most convenient form of these articles. This, however, is not the case. Pure lime is extremely refractory, but readily fusible if any silex is brought in contact with it; and as all fuel contains silex, the simple act of using coal or wood in a furnace built of the best kind of limestone, will soon destroy it. In many instances, the presence of an excess of limestone is advantageous in smelting operations, and is frequently resorted to; in these cases, the inner walls of a furnace may consist of limestone, because the silicious matter of fuel and ore is absorbed by the flux, and little injury is done to the walls. Reflections of this kind generally decide the selection of rocks for fire-proof material, as we shall show hereafter. Native rocks are not often found to be of similar composition, not even in the same locality, for which reasons the selection of fire-proof stone is an operation which must be decided by actual test. It is very well known that the composition of sandstone, clay slate, mica slate, talc slate, gneiss, and granite, and also limestone, varies in different localities, and often in the small compass of a quarry.

Sandstone.—When sand, formed by the disintegration of rocky matter, is washed down in streams and deposited in the beds of large rivers, or the bottom of lakes and oceans, and when such deposits are elevated above water, or become dry land, the fine particles of lime, clay, oxide of iron, and other substances, which adhere to the particles of sand, and which more or less fill the crevices or spaces between the grains, become dry, and form in the mean time a chemical combination with the sand. The consequence of this close and intimate contact between these substances of opposite electrical qualities, is the formation of solid rock, in which the isolated grains of quartz are held together by a larger or smaller quantity of cement. The distinguishing quality of the sandstone for our purpose consists in the kind of cement and the quantity of it. If the cement is lime, we cannot expect the sandstone to be very refractory, for not only does silex melt readily with lime, but the stone becomes brittle when exposed to fire. Peroxide of iron may form a good fire-proof stone with silex, provided the amount of iron is not too large, say not more than five per cent. The red, and often brown sandstone, of the Pennsylvania anthracite formation, is a fire-proof stone of excellent qualities. This stone has been subjected to a slow heat in the earth, which cemented its particles firmly together. The best cement for sand, in the formation of sandstone, is silex itself, and the resulting rock is for these reasons denominated silicious sandstone, in contradistinction from calcareous, ferruginous, or argillaceous sandstone. Silex is soluble in pure water, such as rainwater; and when such a solution is poured upon a bed of sand, it will penetrate and combine with or dissolve some of the sand; the consequence of which is, that the soluble parts are retained by the heavy grains, and these cannot be moved, the soluble silex forming a gelatinous cement for the grains of sand. Sandstone formed in this manner is, as a matter of course, very refractory, and liable to fracture when heat is suddenly applied. Slowly heated, and not exposed to changes of heat, this stone forms a durable hearth-stone in blast furnaces. Stones of this kind are frequently found in the bituminous coal region, and used as hearth-stones. In many respects the argillaceous, in which clay forms the cement, is superior to the silicious sandstone; this refers particularly to those cases where a change of heat is inevitable. Clay does not form a strong cement, and such stones are generally found to be soft in the quarry, but harden on being exposed to the air or heat. These, however, do not generally resist high heat so well as silicious sandstones, and when fluxes come in contact with them when hot, they are soon melted. Sandstones which contain spangles of mica, or particles of pyrites, or which are colored by any metallic oxides, particularly protoxides, are generally not fire-proof; still there are instances where such stones are used to advantage.

In the selection of sandstones for hearth-stones we must be guided chiefly by experience. Coarse-grained stone, such as millstone grit, which occurs in the lower strata of the coal regions, is generally found to be of good quality. The coarse sandstone, in the higher strata of the coal formation, is not often adapted to resist a strong heat and the influence of fluxes, because its cement is chiefly lime, clay, and iron. In these upper strata, the fine-grained stone appears to be superior to the coarse grit. Transition sandstone, or old red sandstone, is generally found to be durable, particularly those kinds in which grains of white quartz of the size of peas, or small beans, are visible. Sandstone is peculiarly suitable to serve as a fire-proof stone; it resists heat to a higher degree than almost any other stone, and if compact, it is less attacked by fluxes than any other kind of rock; it has, besides, the advantage of being found almost everywhere in the United States, and is easily quarried and cut into such forms as are required.

Sandstones may be tested by acids as to their composition, but the result cannot be depended upon, and is of no practical use. The only safe test is that by heat and fluxes. In order to investigate the refractory quality of a rock, a fragment of it is subjected to a gentle heat, which is not much higher than that of boiling water, for at least one week, or longer, after which it may be exposed to a higher heat. The latter is applied in a reverberatory furnace, or in a smith's forge, and should last at least for four or five consecutive hours, the heat being gradually raised to the highest pitch. The fragment, after being gently cooled and broken, must show a compact fracture, not vitrified in any part in the interior; its surface may be glazed, and it should not have lost much in weight. If, after heating it, the interior of the stone is brittle, porous, and friable, or if it is vitrified and strongly colored, it will not resist the influence of fluxes, and it may be considered useless for resisting high temperatures. Quartz is extremely sensitive to changes of heat, and in all cases where it is subjected to them, it should not be used; the changes of heat caused by adding fresh fuel it cannot resist. Sandstone is therefore useless in air-furnaces, and in all furnaces which are subject to alternate charges of fuel, or drafts of cold air, such as puddling-furnaces, the top of blast-furnaces, and all refining and reverberatory furnaces.

Clay and Clay-slate.—This mineral forms extensive rocks, and often whole mountain ridges; it is composed chiefly of silex and clay, but is never free from metallic oxides, and in most instances it contains carbon. The latter substances cause it to be fusible at a low heat, and its use as fire-proof stone is therefore very limited.

Slaty Clay is found in the regions of mineral coal; it forms a most valuable substance for the manufacture of fire-bricks, which are in fact chiefly composed of this clay, particularly in the Western States of the Union. The most valuable deposits of this slaty clay appear to be along the east and west slopes of the Alleghany mountains, still there is no lack of it throughout the western coal basin. Good fire-bricks are extensively manufactured of it; but it is of no use in its raw condition, for it requires a strong fire to make it sufficiently compact for adhering together. Some modifications of this kind of slate, when it contains a large amount of silex, and is stratified, assuming the form of shale, are used as fire-proof stone in furnaces, under steam-boilers, reverberatories, or at the top of blast-furnaces, also for in-walls; but there is little gained in its application; fire-bricks are cheaper in the course of time, because they last longer and require less repair.

Clay.—This substance is not often used in its raw state, but chiefly in the form of bricks, and as fire-proof mortar. Fire-clay is recognized by its color, which is white, and is retained after exposure to a strong fire. Some clays will change their color into a more or less gray, or red, on being calcined; these are not generally very refractory. Good clay, when fresh, emits a peculiarly disagreeable odor, an argillaceous smell; it also adheres strongly to the tongue, when the former is dry and the latter moist; but, there are very good clays along the Atlantic coast which show neither of these signs, at least not in a high degree. The smell depends entirely on organic matter, for which clay has great affinity; it emits therefore that peculiar smell, although it is not actually necessary that organic matter should be present in the clay; breathing upon it may impart it. Clay may contain silex chiefly, and be a good fire-clay; it does not follow that clay which does not adhere to the tongue is not a fire-proof clay. The sources of good clay are feldspathic rocks, and as the latter abound all over the North American continent, particularly along the Atlantic coast, there is no want of good fire-clays. Most of these clays are definite compounds of silex, alumina, potassa, lime, magnesia, oxide of iron, and water, but it is not necessary that a good clay should be a definite compound; on the contrary, the less such is the case the more refractory it is. For these reasons most of the plastic clays are mixed with sand, or pure quartz, previous to forming bricks of them. Clay may be assayed and its composition determined previous to its application, but such an assay is of more interest to the scientific man than to the metallurgist. In some cases, the elements of composition have an influence on the results of the smelting operation. We shall allude to this hereafter. The same test which is used for sandstone, is applied here.

Good clay must shrink uniformly, not crack in drying, and form, after exposure to a strong heat, a compact solid mass, neither vitrified nor brittle. The mixing and tempering of clay has a decided influence on its refractive qualities, and good machinery and good furnaces are required to form good fire-brick. Some clays are plastic, that is, they may be moulded with great facility into any shape, which they will retain in drying and baking. This quality is caused by the presence of more or less soluble silex, and hydrated clay; anhydrous silex is not plastic. However valuable this quality of clay may be to the potter and manufacturer of porcelain, it is of little use to the metallurgist; all we want is, that clay should form a compact, hard substance, which resists fire; the coarse forms in which it is applied do not require a particular degree of tenacity. In order to test clay, it is sufficient to mix it well by hand, and form it into slabs of half an inch in thickness, which are gently dried at first, so as to prevent the formation of cracks, and then exposed to a strong heat. When clay is so fine or plastic as to crack in drying, it is necessary to mix it with sufficient fine, pure, silicious sand, to prevent that evil.

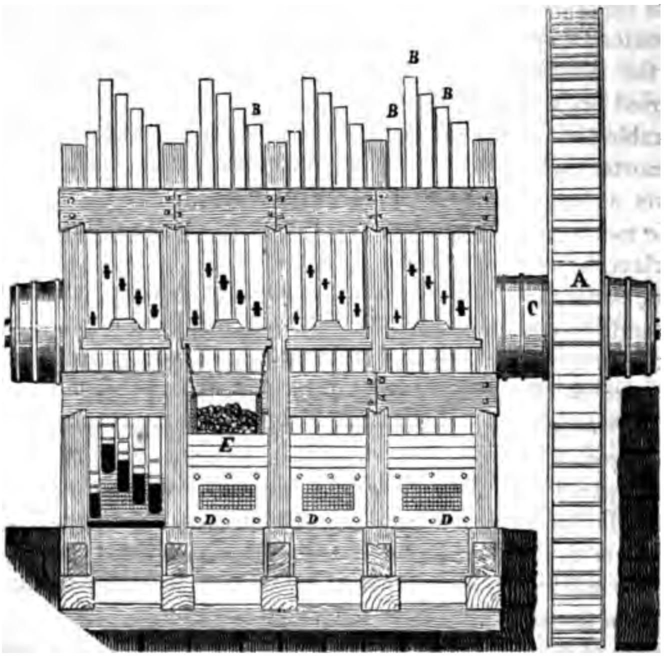
Green, or fresh clay, is not often applied at furnaces; it is, however, used in some smelting furnaces for repairs, and for hearths and boshes, when mixed with a large quantity of sand; also for forming bottoms in reverberatory furnaces, and others. Its chief use is for mortar.

Talcose Slate.—This substance often forms a very durable fire-proof stone, particularly when the slate has been exposed to a strong hardening heat in the native rock. This kind of slate is found along the Atlantic coast; it forms soapstone when soft, but in that variety where it is cemented by heat it is extremely hard. The latter quality occurs frequently in the Southern States; and the former in Maryland, Pennsylvania, New Jersey, and all the New England States. This substance is extensively used as refractory stones in puddling furnaces, for which it is adapted by its resisting the influence of the oxides of metals exceedingly well.

Mica Slate.—This ranges with the talc slate, and in many instances it is very doubtful if the so-called talc slate is not actually mica slate, or merely a modification of it in form, characterized by the extreme minuteness of the leaves of mica. These slates resist fire well, if not too much mixed with metallic oxides, or with too much mica. The quantity of quartz determines the refractibility of the stone. This material is very convenient, because in most instances it is easily quarried and dressed to the desired forms. Chlorite slate, gneiss, porphyry, granite, and similar substances, resist fire in some instances very well; but their quality depends entirely on a peculiar composition. As a rule, these rocks are not very refractory, and are all liable to be broken by heat.

Artificial Stones; Fire-brick.—When natural stones cannot be obtained, or the purpose requires others, the substances of which artificial stones are composed, such as clay and silex, are pounded, ground together, and formed into bricks or slabs of any form that may be desired. Quartz, which is most in use, and in fact the only available substance, besides clay, is pounded in stamping-mills, such as represented in fig. 143. This operation is either performed dry, which causes much dust and premature destruction of machinery, or it is done by passing a current of water through the stamping-box, and gathering the sand in a

Fig. 143.

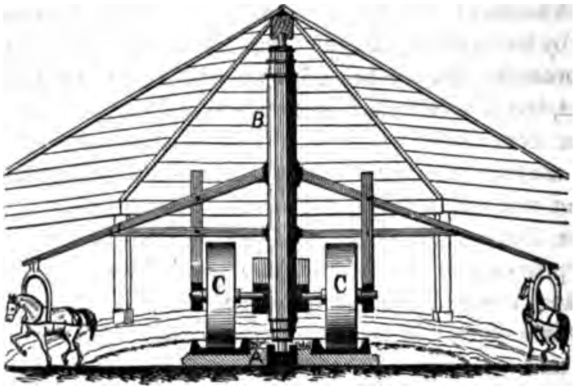


trough, in which it settles, and the water flows off. If the quartz is hard, such as river pebbles, or milky quartz, it may be exposed to a red heat in a roasting heap, after which it may be pounded quite easily.

Of quartz, thus coarsely pounded to the size of a grain of wheat, or smaller, three parts are mixed with one part of plastic fire-clay; the whole well soaked with water, and diligently mixed, forms an excellent fire-proof sandstone, when merely air-dried. Of this mixture, bricks and slabs are easily formed, which may be used air-dried, in reverberatory, puddling, reheating, and all such furnaces, where no actual work or rubbing is done on the surface of the brick; for though they are fire-proof, they cannot resist abrasion when rubbed by solid matter. Bricks of this kind may be baked, but as they require rather a strong fire to make them compact, they are not generally; nor is much gained by a limited heat. These artificial sandstones, or fire-brick, are in many respects superior to the common fire-brick; they are cheap where the materials are close at hand, for the stamping is not expensive, and the moulding and drying causes hardly any expense. An air-dried brick is easily laid, and the joints are secured with remarkable facility, for the brick is suited to absorb the water from the mortar rapidly, which causes the latter to dry quickly; this affords an opportunity of using a large quantity of mortar—and as the mortar itself is but the solution of fragments of brick, the bricklayer's work is done very cheaply. In this case, as in all others, particular attention must be paid to the mixing of the clay and sand; too much labor cannot be expended on this part of the work. In mixing plastic clay with sand, it is the object to bring each particle of clay in contact with a particle of silex, and produce by that means a uniformity of mixture which is at the same time adhesive, and free from friable spots. This material when well prepared is eminently fitted for forming boshes, and even hearths, in furnaces; it may be used in the form of bricks, slabs, or what is the best, rammed down in a moist condition so as to form one solid mass without joints.

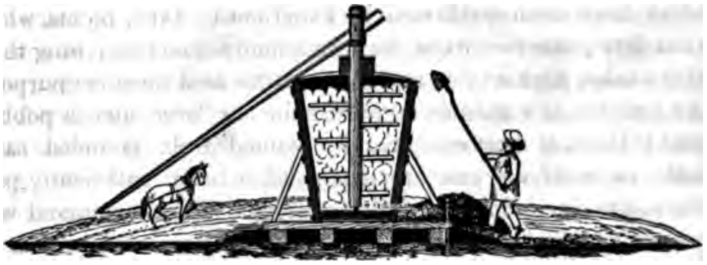
When fire-brick of a finer composition are required, such as are made of slaty clay, or of kaolin, or the silicious fire-clay of the eastern slope of the Alleghanies, it is necessary that the materials should be ground fine; this refers particularly to the slate clay. The clay of the coal regions, which is generally hard when newly dug, is exposed for some time to the atmosphere, under the influence of which it falls to small cubical pieces, and when exposed for a season to frost and the changes of temperature incident to winter, it is converted into a fine meal which is easily ground. When quartz or sand is required for the increase of the refractory quality of the clay, it is mixed with it; or, when too coarse, it is ground first by itself and then mixed in due proportions. The proportion of silex to clay cannot be determined by applying scientific principles; this must be found out by experiments, which are easily made by mixing various quantities and exposing them to the same degree of heat. The quartz used for these purposes must be taken either from pure veins, or large quartz pebbles found in river bottoms. Sand obtained from pounded sandstone, or millstone grit, or river sand, is never sufficiently pure for fire-brick, or for retorts or crucibles. Clay thus mixed with quartz, or pure, is subjected to grinding in a mill similar to that represented in fig. 144. In most cases it is ground dry; some manufacturers grind it wet, because it works faster; the particles, when sufficiently fine, are swept away by the current of water, deposited in a box, and from thence removed to be tempered. The latter operation is frequently performed in the above mill, and in fact is thought sufficient when the grinding is accomplished; but this is not the case. Some clay may require very little work, still no harm is done by much tempering; good clay is often spoiled for want of the proper amount of work. An ill-made brick is porous and light; a good brick is compact and heavy; the first may be good enough for steam-boiler furnaces,

FIG. 144.



but for smelting furnaces, where heat and fluxes, and the motion of fuel, cause abrasion, bricks should be as compact as flint. The latter quality is chiefly obtained by careful grinding and tempering. For this purpose a mill is used similar to those used for mixing loam for common bricks, which is shown in fig. 145. The main part of this machine is an iron or wooden cylinder, of from three to four feet high, and twenty-four inches in diameter. When of wood, it forms an inverted cone so as to admit of being firmly bound by iron hoops. In the centre of this clay-mill is a vertical shaft, provided with some radial knives; this shaft is frequently of wood, but is better when made of iron; the knives must be in all cases of iron. The latter are a little twisted so as to cause the clay to move downward. The tempered clay is thrown in at the top, and the mill always kept full. At the lower end of the cylinder, close to the bottom, is a square hole through which the clay is pressed and issues continually. This square hole is provided with a gate, so as to regulate the quantity of clay which is permitted to pass. If the clay is not sufficiently mixed by passing it once through the mill, the process is repeated; in some cases this is required five or six times. In some instances the knives are provided with projecting points, so as to keep the clay in constant motion, as shown in the engraving, this may be advantageous, but it requires more power than plain knives, and a stronger machine than can be made of wood. This mill, of course, may be driven by horse-power, as shown, or by a water-wheel, or a steam-engine. When circumstances admit, it is advantageous to temper the clay when warm; this causes the air or gas in the pores of the clay to expand and escape, so that a close contact of the particles may be accomplished. It has been proposed to mix carbon, either in the form of graphite, or anthracite dust, or

FIG. 145.



coke-dust, with the clay of which fire-bricks are to be made, but we are not aware that it has been put in practice to any extent. For crucibles such a mixture is used; the black-lead pot is one of the kind, and the pots in which cast-steel is melted are another kind; the latter are generally a composition of clay and coke-dust. For thin pots, and similar articles, we perceive no objection to coal, but in bricks and other heavy masses there are serious objections which have been confirmed by experience. Coal, no matter in what form, causes always the formation of gas when in contact with oxides, such as clay and iron. If the substance is thin, such as a crucible, this gas may escape on the unglazed side; but if the mass is thick, it must escape at the hottest or glazed surface, and is the cause of a premature destruction of the fire-brick. Coal diminishes the shrinkage of clay, and thus far it is advantageous in the clay of crucibles, in preventing their fracture when in fire.

Fire-bricks are not generally manufactured from raw clay, at least not wholly of it; and there is no doubt but that a twice-burnt brick is superior to a brick made of fresh clay. The prepared and ground clay is subjected to one fire, either in the form of brick or in lumps, then ground and mixed with about one-third or one-fourth of fresh clay; this mixture is formed into bricks and baked. Some of our manufacturers do not follow this method, but there is no doubt, if their bricks are good now, they would be far better if baked twice. For this reason, brickbats, ground and mixed with a little fresh clay, will form a superior brick to the original brick, made of raw clay.

Fire-bricks, in order to be baked, are generally subjected to a strong heat, in ovens built in a peculiar manner; this is not necessary, if the bricks are not to be transported far, and if too much clay is not used in the mixture. In the latter case the brick is subject to much shrinkage, and when exposed to the heat in a furnace, the joints between the various layers will separate and allow the heat to penetrate, which now acts on many sides and soon destroys it. All that kind of fire-proof material which must be transported, or in the composition of which a large amount of clay is necessary, must be baked; but those bricks which are manufactured and used on the spot, and which contain a large amount of silex, do not require baking previously to their use. In fig. 146, is represented a vertical section of an oven in which fire-bricks are baked. It is in appearance similar to a porcelain kiln, only not so large. The diameter is generally from 10 to 15 feet, and equally as high, according to the quantity of bricks to be made. One cubic foot of space will contain 8 bricks of 10 by 5 inches. The capacity of an oven is thus easily calculated. One charge will take a week's time—three days for baking, and three for cooling. The oven is built wholly of fire-brick, secured by iron tires and vertical binders. The floor is also formed by fire-brick with draft-holes, or flues, as shown in fig. 147, wherein four fire-places are indicated. This oven may be operated by one or two fire-places, but there is no harm done in having more of them. The fire-places may be without grate-bars in case wood is used as fuel; but when stone-coal is burned there must be grate-bars, which are withdrawn and the stock-holes shut with ashes when the baking is finished. At the top of the oven is a round aperture of about twenty inches in diameter, through which the hot gases escape; when the heat is at the highest degree, this top is shut by an iron plate. At the floor there is an entrance of three feet in height

FIG. 146.

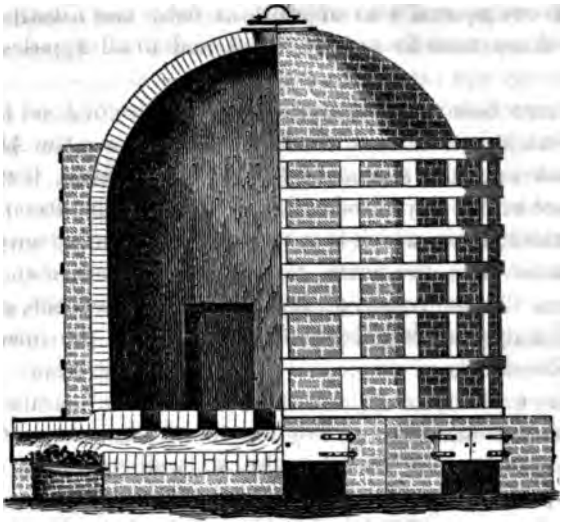
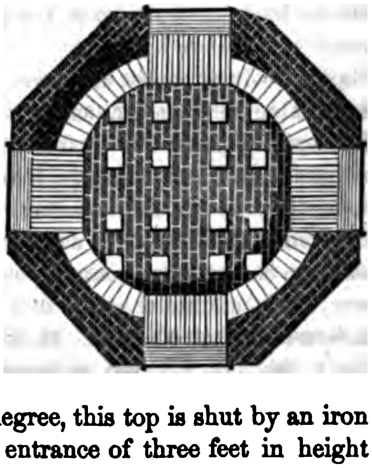


FIG. 147.



and two feet in width, through which the oven is set, or filled with bricks; this is temporarily shut with bricks, which are removed when the heat is finished and the oven cold. Through this door the bricks are also discharged. There are various forms of ovens, and also of mills, in use; the illustrations represent those most frequently found, and to all appearances the best.

The materials requisite for the manufacture of good fire-brick are very abundant in the United States. Between the Alleghany Mountains and the shores of the Atlantic Ocean, there is an abundance of fire-clay, also kaolin, the result of the decomposition of feldspathic rock, which is very common in these regions—and more abundant in the Southern than in the Eastern and Northern States. In the region of the Western coal deposits, an abundance of slaty clay of good quality is found in the lower strata of the formation, of which in Western Pennsylvania first-rate fire-brick are manufactured. In the higher strata of the coal basin, similar veins of clay are found; but these are of an inferior quality, not resisting fire so well as the first kind. Fire-clay, in one or the other form, abounds also in all the Western States; and no doubt can be entertained of its being found in superabundance on the western side of the Rocky Mountains.

CHAPTER V.

Fuel.—In the most extended sense of the term, this embraces all combustible matter, such as carbon, hydrogen, metals, sulphur, phosphorus, and in fact all substances which combine with oxygen and liberate heat. Investigations which are limited to domestic purposes, limit the term fuel to a combination of carbon and hydrogen; but it is advisable for our purposes to consider the term on the most comprehensive scale in applying it to metallurgy. In a limited sense, fuel is understood to comprise only carbon and hydrogen and their compounds, such as wood, peat, lignite, bituminous coal, anthracite, coke, and charcoal, and in some cases the combustible gases derived from the distillation or partial combustion of the above elements.

Flaming Fuel.—The escaping gases of this fuel are the result of its combination with oxygen, or are liberated by heat; and show a more or less opaque flame, white or colored. The visibility of the flame is produced by solid matter heated to a high degree, and its character is indicated by the color of the flame. Fuel which does not produce solid matter in so fine a form as to be carried away by the motion of the hot gases, shows no flame; its gases are invisible. For the metallurgist, the division into flaming and flameless fuel is of the greatest importance; partly because it is indicative of the chemical composition of the fuel, and partly because the operation requires in some cases the one, in others the other, to produce the desired effect. In most instances the flame of fuel indicates the presence of hydrogen, and in consequence free carbon; such is the case in a common candle or oil-flame; but the white color of the top flame at a blast-furnace in which lead is smelted, is not caused by free carbon—it is the visible oxide of lead which is carried away by the gases. The white flame at the top of an iron smelting-furnace is often the result of fine particles of lime, moved by the strong current of the escaping gases. When combustible substances are converted into gases, they are perfectly transparent and invisible. The white flame issuing from a furnace in which flameless fuel is burned, such as charcoal or anthracite, indicates a loss of solid matter; some oxide of metal is evaporated; and if we refer to the color of this oxide, as described in previous pages under the head of Blowpipe, we are enabled to detect the kind of metal which evaporates. If hydrogen is in the fuel, and the color of the flame that produced by carbon, we observe this by either the total disappearance of all solid matter above the flame, or a deposit in the form of a black smoke, while the oxides of metals produce a deposit whose color is indicative of the metal. In most cases, where metallic ores are smelted in contact with the fuel, the presence of hydrogen is found to be either injurious to the quality of the metal produced, or to the operation; for these reasons such fuel is charred; that is, those substances which are injurious are partly or altogether driven off by means of heat previous to its application.

The division of flaming and flameless fuel is particularly appropriate in our case. Heat is distributed partly by convection, and partly by radiation. Invisible gases do not radiate heat; the presence of solid matter is required to produce radiation; and the latter depends in its quantitative effects on the color of the radiating medium; white will produce the strongest, black the least effect, and the intermediate colors in proportion. It is therefore easily comprehended that wood-charcoal is a very imperfect fuel in a reverberatory furnace, because it does not produce a visible flame. The hearth of a puddling furnace cannot be heated to a high degree by such fuel, particularly when the reflecting-roof is blackened by smoke, or vitrifying oxides of iron. If in this case the original white color of the fire-bricks could be retained, the effect of the fuel would be stronger; but as that is almost impossible in any furnace in which metals are melted, the flameless fuel is an expensive one in a reverberatory. For this reason, wood or bituminous coal is superior to charcoal in the reverberatory furnace. Anthracite, being also a flameless fuel, is notwithstanding in extensive use in reverberatories, and works admirably well. The cause of this must be found in the general application of blowers to the grates of these furnaces. With bituminous coal and wood the common draught is strong enough to carry small particles of carbon, either chemically combined with hydrogen and liberated when the latter is oxidized, or as fine particles with the current of the hot gases; these particles of carbon, in either one or the other form, are the solid matter which causes the flame to be visible and radiate heat. Anthracite is almost free from hydrogen, therefore no carburetted hydrogen is formed; it is very compact, and no particles of coal can be carried off by a gentle draught. In applying a strong draft, or blast, small particles of coal are torn loose, which float or are suspended in the gases, form a visible body, and the flame then has the capacity of radiating heat. However important may be the application of this principle in reverberatory furnaces, it has little or no value in the furnaces of steam-boilers, or where heat is conducted by the motion of the gases, as is the case in heating hot-blast. In some instances an illusory advantage is derived from flaming fuel under a steam-boiler; but this is caused by the imperfect form of the boiler, and in all cases includes a waste of fuel; the flame is here an extension of the process of combustion, which when perfect ought to be realized in the furnace. A steam-boiler, and similar apparatus, needs but the hot gases in order to consume fuel to advantage, no radiation of heat being required.

Composition of Fuel.—Omitting small quantities of foreign matter, the flameless fuel consists chiefly of carbon, and flaming fuel of carbon and hydrogen, so far as this refers to flame produced by natural draught. The amount of foreign matter, which is not generally considered as fuel, such as sulphur, iron, silex, &c., varies greatly according to the kind of fuel. We insert on the next page tables which show the relative value of the most common articles of fuel, which are of interest to the metallurgist. From these tables we obtain the value of that fuel which is most commonly used in smeltworks, and when we consider that equal weights of dry wood afford in all cases a nearly equal amount of heat, and also an equal weight of charcoal, it is not difficult to estimate the value of a cord of pine wood, or that of white oak for making charcoal. When a cord of shell-bark hickory is worth one dollar, that of white ash is worth 77 cents; beech 65 cents; sugar maple 60 cents; white oak 81 cents; yellow pine 54; poplar 52; and Lombardy poplar only 40 cents. The estimation of the value of fuel by its evaporative power, is not of much use to the metallurgist, because in most cases he employs the pure carbon only. Anthracite coal is therefore of a higher value than bituminous coal to the smelter, because he has nearly the full weight of carbon in a certain weight of coal, while a weight of bituminous coal furnishes on an average only half its weight of coke. An equal weight of dry or fresh charcoal contains in all cases an equal amount of carbon, and furnishes the same amount of heat.

As a rule, we may say that equal quantities of pure carbon produce equal quantities of heat, but this is not in practice exactly the case. In melting iron in a reverberatory, a large quantity of heat is lost, and we obtain but little heat compared with the amount produced. If the temperature is higher in melting iron than in melting lead, we lose not only in proportion as the heat increases, but also according to the length of time which is occupied in the operation. The amount of fuel necessary for melting metals cannot therefore be calculated by taking their capacity for heat into consideration, as is the case in determining the amount of fuel requisite for heating or evaporating a certain quantity of water, for in that case nearly all the heat liberated by the fuel is received by the water or steam, while at least ¾ and more must be lost in melting iron. The time in which the melting or heating operation is performed is also of great consequence. In a well arranged cupola, cast-iron may be melted by 10 per cent. of its weight of fuel; in an air-furnace it requires the use of 50 per cent., and in a blast-furnace as much as twice the weight of iron produced; for which difference there is no apparent cause but the length of time used in melting. In order to save fuel, it is necessary to perform metallurgical operations in the shortest time possible.

Table showing the Value of Wood.

Kind of Wood.	Specific gravity of Wood.	Pounds of Wood in a cord. Adp.	Per centage of Charcoal.	Specific gravity of the Charcoal.	Pounds of Charcoal in a bushel.	Bushels of Charcoal f'm a cord of dry wood.	Relative value of dry wood. Hickory. 1.
White ash,	·772	3450	25·74	·547	28·78	31	·77
White beech,	·724	3236	19·62	.518	27·26	23	·65
Butternut,	·567	2534	20·79	·237	12·47	42	·51
Red cedar,	·565	2525	24.72	·238	12·52	50	·56
Chestnut,	·522	2333	25·29	·379	19·94	30	·52
Dogwood,	·815	3643	21	·550	29·94	26	·75
Shell-bark hickory,	1·000	4469	26·22	·625	32·89	36	1·00
Hard maple (sugar),	·644	2878	21·43	·431	22·68	27	·60
Soft maple,	·597	2668	20·04	·370	19·47	28	·54
Magnolia,	·605	2704	21·59	·406	21·36	27	·56
Chestnut oak,	·885	3955	22·75	·481	25.31	36	·86
White oak,	·855	3821	21·62	·401	21·10	39	·81
Black oak,	·728	3254	23·80	·387	20·36	38	·71
Red oak,	·728	3254	22·43	·400	21·05	30	·69
Yellow pine,	·551	2463	23·75	·333	17·52	33	·54
Jersey pine,	·478	2137	24·88	·385	20·26	26	·48
Pitch pine,	·426	1904	26·76	·298	15·68	33	·43
White pine,	·418	1868	24·35	·293	15·42	30	·42
Poplar, yellow,	·563	2516	21·81	·383	20·15	27	·52
" Lombardy,	·397	1774	25	·245	12·89	34	·40
Sycamore,	·535	2391	23·60	·374	19·68	29	·52
Blackwalnut,	·681	3044	22·56	·418	22·	31	·65

Table showing the Value of Coal.

Kind of coal.	Specific gravity.	Pounds of coal in a bushel Avoirdupois.
Lehigh coal, ...	1·494	78·61
Schuylkill.	1·453	76.46
Susquehanna.	1·373	72·25
Rhode Island, ...	1·438	75.67
Cannel coal, ...	1·240	65·25
Liverpool, ...	1·331	70·04
Richmond, ...	1·246	65·56

The quantity of oxygen consumed by any combustible matter indicates directly the quantity of heat liberated; the effects, therefore, of fuel, are directly as the quantity of oxygen consumed. It does not make any difference if the oxygen combines with carbon, hydrogen, sulphur, or any other substance. This affords an easy means to determine the quantity of heat which may be liberated by fuel, for we need only to find the quantity of oxygen consumed in order to know the quantity of heat which may be liberated by the fuel. The means by which an assay of fuel is made have been detailed in former pages. All that is required to succeed well in such an assay is the use of pure litharge, free from metallic lead, from minium and other substances, and the application of an excess of it. Thirty-four parts of pure lead, which is found in the form of a button, is equal to one part of pure carbon; the fuel may contain other combustible substances than carbon and hydrogen, the lead represents its capacity for generating heat. This method of assaying is not quite correct, but sufficiently so for practical purposes; the amount of the resulting lead is however never too large.

One pound of oxygen in combining with fuel will liberate heat equal to 29·5, or nearly sufficient to raise 30 pounds of water from 32° to 212°, or from freezing to boiling. From this we may conclude that one pound of oxygen liberates, in combining with other matter, $180° \times 30 = 5400°$ of heat. If we know the capacity of a substance for heat, we may easily find how much fuel is required to heat it to a certain degree. In assaying fuel by means of the oxide of lead, we find exactly how much oxygen has been consumed, for 100 parts of litharge are composed of 92·83 metal and 7·17 oxygen. In order to consume one part of oxygen, $\frac{92{\cdot}83}{7{\cdot}17} = 12{\cdot}9$ parts of lead must be produced. We may, therefore, calculate the capacity of fuel for generating heat, either by estimating the quantity of oxygen which has been consumed, or the quantity of lead produced. These investigations show the quantity of heat which may be liberated from a certain kind of fuel, but they do not show the degree of heat which may be produced.

Intensity of Heat.—This may also be called qualitative heat, pyrometric heat, or degree of heat. It is, with the means at present known, not in our power to measure a high temperature directly. We may measure by a thermometer 600°; beyond this, the direct measurements are rather uncertain. We may arrive by calculation at an approximation of the degree of heat developed by a certain kind of fuel. The direct measurement of a high heat by a simple instrument is in many instances much needed, and a good pyrometer is yet a desideratum. However, there is no simple instrument known for this purpose, and we are obliged to estimate the degree of heat by investigating the composition of the fuel. All the heat generated by combustion must be contained in the products of combustion; from the latter it is absorbed by some means or other. In all instances, it is necessary to convert the heat obtained from these products of combustion into an equivalent of heated water, because in that case the operation is more simple than when calculated for commingled matter. The degrees of heat thus obtained may be applied to other substances by comparing their specific capacity for heat, and the space in which combustion is performed.

One part of carbon, on being converted into carbonic acid, absorbs 2⅔ parts of oxygen; the quantity of heat generated must be therefore 5400° × 2⅔ = 14,364°, or taking a simple figure, 14,000°; that means, one pound of pure carbon will heat 14,000 pounds of water one degree higher, or one pound of water 14,000 degrees higher. In this instance we may, for the sake of convenience, convert the qualitative heat into quantitative, and reverse it, but this operation is not applicable in practice. When one pound of carbon is converted into carbonic acid, it forms 3⅔ pounds of that gas, which must be considered as containing the whole of the heat generated; and if no other gases are present, that is, if the combustion is performed by pure oxygen and pure carbon, in an absolutely non-conducting and non-absorbing apparatus, the degree of heat generated in that combustion must be $\frac{14{,}364^\circ}{3{\cdot}66} = 3900^\circ$, provided the specific heat of carbonic acid is equal to that of water. When the latter is 1, the specific heat of carbonic acid is 221, which brings the temperature at the moment of combustion between pure oxygen and pure carbon to $\frac{3900^\circ}{{\cdot}221} =$ 17,642°. This degree of heat can never be produced in practice, for we never burn pure carbon in pure oxygen; and the other conditions requisite to generate it cannot possibly be complied with.

In practice combustion is carried on by means of atmospheric air; and as the quantity of nitrogen, and its capacity for heat, is such that it absorbs nearly twice the amount of heat as the newly formed carbonic acid, the above degree of heat must be reduced to $\frac{17,642}{3}$ = 5,880°. Common fuel is not often pure carbon, and charcoal has water and air condensed in its pores; this must be heated, and the heat absorbed must be subtracted from the above. In wood there is always a large quantity of water; this is converted into steam, and the heat absorbed must be substracted from the above. Anthracite coal should furnish the largest quantity of heat from the same weight of fuel, because it contains little hydrogen, and little air or water is condensed in its pores. Bituminous coal should furnish an equally high temperature, and an equal amount of heat as anthracite; but this is not the case, chiefly on account of its softness, and its volatile substances, which carry off a large quantity of carbon, which is either not burned at all, or imperfectly, and thus escapes from the place of immediate combustion.

In practice, we never obtain the degree of heat which has been calculated from these elements. It has been found that, if not the greatest intensity of heat, at least the greatest economy in fuel, or quantity of heat, is obtained when twice as much air is conducted through the fuel as is actually necessary for combustion. If now we assume the temperature of the atmosphere to be 32°, the temperature in the grate can at best be only $\frac{5,880}{2}$ = 2,940°. The quantity of free oxygen in a re-heating furnace for iron is about half as much more than that which has been consumed by the fuel, which will bring the temperature in the re-heating furnace to $\frac{5,880 \times 2}{3}$ = 3,920°; this is the most favorable condition under which fuel can be burned; we can by no means obtain a higher heat from the best and purest fuel. To feed fuel with exactly that amount of oxygen required for the formation of carbonic acid, is almost impossible in practice; and it has been found that when the quantity of oxygen is not greater than that required for the formation of carbonic acid, a loss of fuel and a low degree of heat is the consequence. All the oxygen is not absorbed in passing through a low stratum of coal; the contact of oxygen with carbon is thus limited; and as part of it is converted into carbonic oxide, which of course furnishes but half the quantity and half the degree of heat, we cannot expect the highest results in practice.

Hydrogen does not furnish a high degree of heat; it gives off a large quantity, but not of good quality, and the apparently higher heat in the combustion of bituminous coal compared with that of anthracite or charcoal, is derived from the fine particles of carbon which float in the gas. Hydrogen absorbs a large quantity of oxygen, and should furnish much heat; but the result of its combustion is steam, which has a capacity for heat four times greater than carbonic acid gas; it absorbs therefore four times as much heat as the latter, in order to be heated to the same degree; or what is the same thing, the temperature must be four times lower. Besides this defect of hydrogen compared to carbon in respect to qualitative heat, its product of combustion is nearly three times as voluminous; the heat spreads, therefore, over a larger space, and consequently loses in direct proportion in intensity. These investigations show distinctly the superiority of carbon over hydrogen, and also over most other combustible substances. It is beyond the limits of this work to enter farther into these speculations; it is sufficient to show the arguments upon which some of our conclusions in subsequent pages are based. According to the foregoing, the degree of heat at the point of combustion must be as represented in the following table.

	Degrees of heat produced by combustion	
	In pure oxygen,	In atmospheric air,
Carbon	17,770°	4,424°
Carburetted hydrogen (coal-gas)	10,843°	3,829°
Alcohol	8,137°	3,438°
Hydrogen	5,709°	2,899°

These numbers are not, and cannot be, quite correct, but approximate to the actual temperature, and afford elements for comparison.

When we consider the quantity of heat generated by fuel, the capacities of it appear quite different from the above, as the following table shows:

One part by weight of each of the following substances will heat the subjoined weights of water from 32 to 212 degrees.

Hydrogen, ...	236	weights.
Pure carbon, ...	78	“
Charcoal, ...	75	“
Dry wood, ...	36	“

Wood with 20 per cent. moisture,	27	"
Stone coal,	60	"
Peat,	25 to 30	"
Alcohol,	67	"
Oil, fat, wax, &c.,	90 to 95	"

This table may be applied for degrees of heat as well as for weights. It does not make any difference if one pound of carbon heats 78 pounds of water from 32° to 212°, or heats one pound of water to 78 × 180°, provided that degree of heat can be produced by the fuel.

Specific Heat.—As the specific heat of the products of combustion, as well as those substances which are to be heated, are of some consequence in calculations of this nature, we subjoin a table of specific heats of various substances.

Specific Heat of Bodies. *Water*=1·00.

Glass under which all slags may be included,	·1770
Iron,	·1098
Copper,	·0949
Zinc,	·0927
Silver,	·0557
Platinum,	·0355
Mercury,	·0330
Lead,	·031
Tin,	·056
Bismuth,	·029
Carbon,	·257
Phosphorus,	·188

So far we have investigated all that may be of general interest in respect to fuel, and shall now proceed to the examination of particular kinds of fuel.

Wood.—The fuel most generally in use in metallurgical operations is wood, either in its raw form, that is, green; or air-dried, kiln-dried or charred. An equal weight of dry wood furnishes an equal weight of charcoal, or an equal amount of heat. But, as it would be too laborious besides being uncertain, to weigh wood in order to determine its value, the wood is measured, of which a cord of 128 cubic feet forms a unit; and by applying the values found in a previous table we obtain the value of a cord of wood of the various kinds. In measuring wood, the billets should be of uniform length, that is, four feet from end to shoulder; this causes the billets to be on an average from 3 to 6 inches longer, from one extreme point to the other. In piling the wood the billets must be thrown in gently; not skilfully laid, so as to cause open spaces. A cord of wood measures eight feet in length and four feet in height, closely piled, with billets four feet long. In uniformly piled wood we may calculate on a certain weight of either green or dry wood, and by referring to the table, page 489, all the data which are worthy of attention may be found.

A division into soft and hard wood is an imperfect classification, for there is no distinct limit between the two. The same tree affords often hard and soft wood. This subject is of little interest to the metallurgist, and hardly worth notice. The chemical composition of wood with that of the ashes, and its capacity for the absorption of water, is of more importance to us.

Composition of the Fibre.—The composition of the woody fibre, dried at 212°, is shown very little to vary in the various kinds of wood, as the following table indicates:

	Carbon.	Hydrogen.	Oxygen.
Pure woody fibre . .	52·65	5·25	42·10
Oak, ...	49·43	6·07	44·50
Black poplar . . .	49·70	6·31	43·99
Pine, ...	49·95	6·41	43·65

For these reasons the quantity of heat obtained is nearly the same for all kinds of dry wood, as shown below:

One part of	Oak,	reduced in the crucible,	14·05	parts of litharge.
"	Linde,	"	14·43	"
"	Beech,	"	14·00	"
"	Poplar,	"	13·10	"
"	Pine,	"	13·27	"

From these two tables we readily draw the conclusion that equal quantities of dry woody fibre must furnish equal quantities of charcoal.

Amount of Water.—This is not uniform, it varies greatly in different kinds of wood. In 100 parts of green wood it was found that

Willow,	contained	26·0	parts of water.
Sycamore,	"	27·0	"
Ash,	"	28·3	"
Oak,	"	34·7	"
Horse Chestnut,	"	38·2	"
Pine,	"	39·7	"
Red Beech,	"	39·7	"
Italian Poplar,	"	43·2	"
Black Poplar,	"	51·8	"

The quantity of hygroscopic water, as shown above, is not uniform throughout the year; it is smaller in winter than in fall and spring, and largest during the summer season. The difference is considerable, as shown below.

	Quantity of Water in the Months of	
	January.	April.
Ash,	28·8	38·6
Maple,	33·6	40·3
Chestnut,	40·2	47·1
White Pine,	52·7	61·0

The quantity of water thus found in the live tree, is greatly diminished by exposing the chopped wood to dry atmospheric air, which, when the operation is well performed, reduces the quantity of water to a nearly uniform standard. 100 parts of wood, thus dried, were found to contain:

Oak,	16·64	parts of water.	Maple,	18·63	parts of water.
Pine,	17·53	"	Linde,	18·79	"
Beech,	18·56	"	Poplar,	19·55	"

This shows that no great error is committed in assuming the presence of 20 per cent. of water in air-dried wood. The quantity of water in the air-dried wood may be expelled almost entirely, without altering the fibre, by exposing it to a heat of 270°. Kiln-dried wood is generally dried at a higher heat, and undergoes in consequence a partial decomposition; this mode of drying is necessary when perfectly dry wood is required, because wood dried at a low heat absorbs moisture as soon as it is exposed to the atmosphere, and absorbs during the first 24 hours from 10 to 15 per cent.. By soaking green wood in water, a large quantity of combustible substance may be extracted, which amounts to 3, or even 4 per cent. of woody fibre.

Ashes.—The quantity and composition of the residue from the combustion of wood is very variable. The ashes in the following kinds of wood amounted to the annexed per centage.

100 Parts of	Contained Ashes.	100 Parts of	Contained Ashes.
Oak,	2·50	Pine,	1·24
Linde,	5·00	Beech,	3·25

The quantity of ashes is not uniform, throughout the whole, or in all parts of a tree, and it appears that in old trees of the same kind the quantity of ashes is larger than in saplings. The following table refers to kiln-dried wood:

Age.	Kind of Wood.	Part of the Tree.	Quantity of Ashes per cent.
120 years,	Oak,	Trunk,	2·43
"	"	Branch,	2·03
70 "	"	"	2·10
30 "	"	"	1·45
70 "	Beech,	Trunk,	·86
120 "	"	Branch.	1·93
75 "	"	"	1·70
20 "	"	" (very young)	1·50

Not only the quantity of ashes is of interest, but its chemical composition has a bearing on metallurgical operations. The number of elements in wood-ashes is very great, and a close examination of the subject belongs to chemistry more than to our labors; still we may point out the most characteristic qualities.

Kind of Wood.	Per centage of Ashes.	Silex.	Potash and Soda.	Lime Carb.	Magnesia.
Beech (charcoal),	3·3	6·8	64·1	42·6	7
Oak wood,	2·5	4	67·6	54·8	6
Pine (charcoal),	10·24	6	83	42·3	10·5
Wheat straw,	4·4	11·0	50	5·8	

We have omitted to insert here small quantities of oxides of iron, of alumina, and of manganese; also sulphur in the form of sulphuric acid, phosphoric acid, chlorine, and carbonic acid; because the quantities are either small, or the matter itself, such as the various acids, is decomposed in the smelting-furnace. Of all the parts of the composition of ashes, those of potash, soda, lime, magnesia, and iron, form the most interesting—in fact all electro-positive elements—because these serve as fluxes for silex; and where the minerals are brought in contact with the fuel, the presence of an alkaline ash is of advantage. Subjoined we insert a table showing the amount of potash present in various kinds of wood and plants; and as this shows the quantity of the strongest alkali, we may estimate the quality of ashes in metallurgical operations accordingly.

1000 Parts of	Contain Potash
Pine wood,	0·45
Poplar "	0·75
Beech "	1·45
Oak "	1·53
Willow "	2·85
Maple "	3·90
Wheat straw,	3·90
Barley "	5·80
Cornstalk,	17·50
Wormwood,	73·00

In some of these ashes there is a large quantity of silex, and but little lime and other alkaline earths—such is the case in wheat straw; and in calculating ashes as fluxes, we are to consider this circumstance.

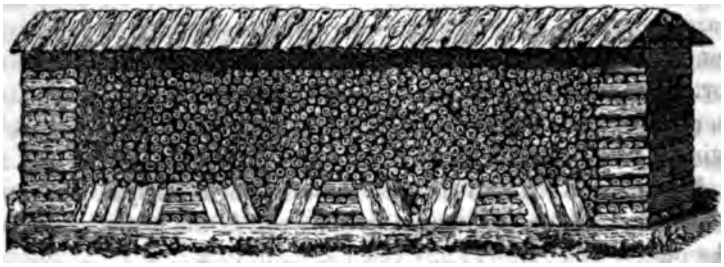
Flammability.—In practice the quality of wood is frequently classified according to the facility with which it burns; and it is generally assumed that soft wood burns more vividly than hard wood. This is not actually the case; it depends very much on the absence of water, and the kind and quantity of ashes. Soft, or light wood, is sooner dried than hard wood, and is consequently suitable for use in a shorter time. Dry hickory is more inflammable than most other kinds of wood, and is also one of the hardest kinds. The presence of water in green wood diminishes the inflammability, in consequence of its absorption of heat, and when the amount of the latter is great the wood ceases to be combustible; all the heat which may possibly be generated in burning, is absorbed by the hygroscopic water in being converted into steam. The presence of water in any fuel causes a serious loss of heat, particularly in wood; because its porosity adapts it more than any other fuel to absorb water. The quantity of heat absorbed by water in being converted into steam, may be calculated with great precision; and as all air-dried wood contains from 20 to 25 per cent. of hygroscopic water, we may easily determine the amount of heat thus lost. When pure carbon, or perfectly dry wood, produces a temperature of 4000° —which may be higher or lower in some cases—and if in such fuel there is 25 per cent. of water, the total quantity of heat generated by 100 pounds is reduced to 75 pounds which produce heat, and 25 pounds which absorb it. This loss is the more serious as water requires a large amount of heat to be converted into steam, or gas, which heat is not recovered but by the condensation of the steam into the original fluid form of water. The latter condition is never obtained in the common process of combustion, particularly in metallurgical operations, the water always escaping in the form of steam. When kiln-dried wood produces 4000° of heat, it has been calculated that air-dried wood cannot produce a higher heat than 3000°; and as the quantity of water increases, the temperature, and consequently the amount of available heat, is greatly diminished. The above figures are not absolutely true; they merely approximate to the real loss, for it is not possible to calculate the exact amount.

Drying of Wood.—In order to avoid the loss of heat caused by the presence of water, and also to produce the degree of heat required in particular operations, such as melting in reverberatories; and in order to avoid loss of metal by the oxidizing quality of steam, which is particularly apparent in reheating and puddling iron, the wood is dried, either naturally, by exposing it to the influence of the atmosphere in the open air, under sheds, or by drying it artificially in heaps, ovens, or kilns. In many instances air-dried wood, or even green wood, is preferable to perfectly dry wood; such is the case in roasting ore, burning lime, and in all operations by which carbonic acid, sulphur, phosphorus, and other volatile substances are to be expelled; or where a metal is to be oxidized, or a metallic ore is to be more highly oxidized. The presence of the vapors of water has here a threefold advantage—it prevents a too high heat, carries off the volatile matter, and furnishes oxygen for oxidization. This effect may be produced by atmospheric air, but not as perfectly as by means of hot steam. If a sulphuret is to be decomposed, the degree of heat should be low in order to prevent its melting—the presence of water will more fully effect this object than any other means. When atmospheric air only has access to the heated sulphuret, oxide of metal and sulphurous acid will be formed; the latter is heavy and not so easily carried off—in the presence of steam it will escape with the latter. If, in this case, water is the oxidizing agent, oxide of metal and sulphureted hydrogen is formed; and the latter being very light, is easily removed. In all cases of roasting, particularly sulphurets, air-dried wood, or, still better, green wood in the lower layers of the pile, is preferable to any other kind of fuel.

Air-dried.—The most simple means of drying wood, is to cord it in the woods in dry and open places, upon rocky or stony ground, so as to admit a free circulation of air below the piles. Swampy or damp ground is not favorable to this operation; and when no other opportunity is afforded to facilitate the removal of moisture, the cords should be set upon a grating formed of dead timber, so as to bring the lower billets as high above ground as possible. In the latter instance it is advisable to cord higher than four feet, if the means are afforded, so as to bring most of the wood high above ground. Air-dried wood is not only of great advantage where it is used directly in the furnaces, but also for charring. Charcoal is obtained in greater quantity, and better in quality, when made from dry than from damp or green wood. The time required for reducing the quantity of water as low as possible, varies of course according to the kind of wood. Light, porous, old wood, is sooner dried than hard, close, young wood. On rocky dry ground it requires less time than on damp ground, and high piles, when covered, will soon lose their water. Wood cut in fall and winter is sooner dry than that which is cut during spring and summer, and has besides the advantage of being more close and compact. Six months, and from that to twelve months are sufficient time for drying any kind of wood, and in favorable locations even less time is sufficient for evaporating the water. In all cases wood should be air-dried before it is exposed to the heat of a drying oven or the charring kiln.

When wood is to be used air-dried, and that is to be accomplished to the highest degree, the billets of split wood are piled in high heaps, either in or near the smelt-works, or so far removed that no danger of kindling them accidentally by flying sparks is apprehended, or in the woods, in case it is safe to leave it there for a longer time. For if a large pile takes fire the losses are generally great. The best form of piling wood is represented in fig. 148. At each end of the pile a square pillar is erected of billets crossing each other, and laid as open as possible, so as to admit of the free circulation of air; these pillars must be strong, and may be a little inclined towards each other. They are four feet square, or the length of the billets. Between these two end pillars, in distances of eight feet, low pillars are erected, about three feet high; these are sloped on two sides, so as to form a pyramid. The spaces between these various pillars are occupied by billets, nearly vertical, so as to form open spaces for the access of air; these upright billets are a little inclined, so as to form a firm foundation about three feet high, upon which the wood may be piled to any height which it is safe and convenient to adopt. When such a pile can be erected at the side of a hill, or is made accessible by other means, a height of from 20 to 25 feet may be reached; in other cases it ought to be at least from 12 to 15 feet high. The top of the pile is either covered by flat billets, by slabs, or by boards, so as to form a roof from which the rainwater easily flows off, and may be carried beyond the walls of the pile. The lower part of the wood-pile being thus accessible to the air, it is necessary to form as many and as large spaces as possible throughout the whole height, in order that there may be a series of draught holes or chimneys for its thorough circulation. From this it is evident that the height of the pile is of considerable influence in this operation, for it is the cause of the motion of air, and the higher it is, the stronger that motion must be.

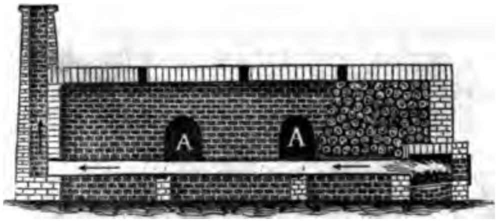
Fig. 148.



Some wood-choppers possess a remarkable skill in cording wood to their own advantage, and such should be employed to set a pile of this kind. When the means are afforded to erect wood-piles under sheds, or better still, near or in the buildings of the smelt-works, the process of drying may be greatly facilitated, and the effect of the wood augmented, by carrying off a larger quantity of moisture than can be accomplished in the open air. In some instances, the wood is cut and split into shorter and smaller pieces than billets of cord-wood generally are; when this can be done while the wood is green, the process of drying is remarkably shortened.

Kiln-dried.—For most of the metallurgical operations, air-dried wood contains too much moisture, which, if the loss in heat is not considered, must be removed in order to prevent oxidation by the vapor of water which is thus brought into the furnace. In all processes of reduction, the hygroscopic water must be removed before bringing the fuel into the furnace; and in melting and heating metal it must be removed, in order to prevent oxidation and consequent loss of metal. The best means for drying are ovens, or kilns, of a capacity of from 25 to 100 cords of wood. These ovens are variously constructed, of which we shall furnish a few examples. The main expense in drying wood in kilns, is caused by handling the wood; that, together with the cost of the kilns, is the reason why kilns are not more generally used. In using air-dried wood, ¼ of the heat generated is in most cases lost in evaporating the hygroscopic water. If there was no other consideration than this, it would be a sufficient inducement for drying wood artificially, particularly where the price of this fuel is high. We annex, in fig. 149, the drawing of a kiln, which is rather expensive in the first cost of erection and also in its operation. This kiln forms a long chamber of from 12 to 20 feet in length, 10 feet high, and about 9 feet wide, for

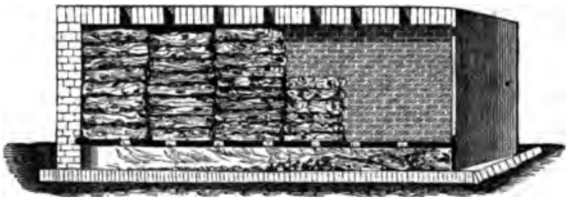
FIG. 149.



two lengths of billets. The wood is charged through openings, marked A A, in the sides of the furnace, which are shut either by iron doors, or by bricks temporarily. Throughout the length of the kiln and in its bottom is a cast-iron pipe, of from 16 to 18 inches diameter in the clear. This pipe communicates at one end with the furnace or fire-chamber, and at the other with the chimney. Instead of one, there may be two or more pipes. The whole furnace and chimney is, or may be, built of red bricks, secured on the outside by binders and stays of wood or iron. When the furnace is charged with wood, of which the lowest layer, to prevent its catching fire, ought to be about a foot from the iron pipe, the side-doors are shut, well-secured, and made air-tight by clay or loam. Fire is kindled in the furnace grate, the heat and smoke of which passes through the iron pipe into the chimney, and is consequently not brought in contact with the wood. The fuel used in the fire-chamber, may be dead-wood, sawdust, bark, slack coal, peat, or in fact any worthless substance which furnishes heat sufficient for drying. The vapors of water escape from a series of small square openings in the roof, which may be shut by a brick or slab when required. The object being merely to expel water, the temperature in the drying chamber ought not to be much higher than the boiling heat of water; at least not beyond 250°. This condition is observed through the holes in the roof, which serve in the mean time to regulate the heat uniformly over the whole of the chamber, by shutting or opening one or the other. A heat, or one charge, may be accomplished in 48 hours, that is, 24 hours for heating, and 24 hours for cooling, discharging, and charging again.

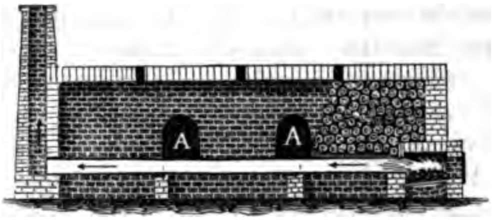
A kiln somewhat more suitable to perform well, if attention be daid to the heating of it, and requiring less labor in charging and discharging than the above, is represented in fig. 150. This

FIG. 150.



oven may be from 20 to 30 feet or more in length, 10 or 12 feet high, and equally as wide. It is built of common red bricks, having walls 18 inches thick, secured by wooden stays. At each of the long ends is a double gate of wood, plastered over on the inside with loam, which, for the sake of greater durability, may be moistened with brine. These doors are of such a size, that a loaded wagon or cart may enter backwards directly into the oven, and there be unloaded with great facility. When the oven is filled, the doors are shut, and the access of fresh air is prevented with clay. Throughout the length of the bottom of the oven is a flue, covered by double or triple layers of bricks, which are provided with openings for the escape of the heat. Fire is kindled at both ends, or at one end (A) below the doors, as the case may require; and the hot gases and smoke pass through the wood in the chamber, where they absorb the moisture, and thence out at a series of small openings, which are shut or opened, as in the kiln fig. 151. This kiln may be heated by an iron pipe, like the one last mentioned. This method is to be preferred, as there is less danger that the wood will take fire, which often happens if the oven is not well watched. When it occurs there is always a considerable loss of fuel. All the openings of the oven, fire-places, doors, and top, must now be well stopped up to prevent the access of air to the interior; any fire may thus be easily suffocated.

FIG. 151.



The ovens described above have disadvantages, such as will hardly admit of their extensive use in this country. The operation is expensive in consequence of the repeated handling of the wood. A cord of wood cannot be loaded or unloaded, or in fact thrown from one place to another, for less than 10 cents. To load wood from a pile in a yard, it must be twice handled, or two men are required; to charge it into the oven, and to discharge it, each requires two handlings; and to unload it, one: in all, the wood must be seven times taken in hand before it is dried. When we add fuel and labor at the kiln, a cord of wood cannot be dried for less than one dollar. When a cord of air-dried wood costs $3, the expense of drying will raise it to $4; thus the advantages derived from drying are absorbed by the expense which it causes. When the wood is cheaper than $3, it will admit of it; when it is higher than that price there may be some small advantages. The chief expenses arise here from the handling and transportation of the wood; and, as this may be considerably lessened by proper arrangements, and as it is, in most cases, advantageous to kiln-dry it before using it in any smelting operation, we propose the following oven and arrangement for this purpose. In fig. 152 is represented a drying oven, such as is shown in fig. 153; with the only difference, that cars running on a railroad track, and made entirely of wrought iron, are loaded in the yard, then pushed into the hot oven, where they remain until the wood contained in them is dry; they are then taken from the oven directly to the smelt-works, and unloaded as the wood is gradually used in the furnaces. By this means all of the handling of the wood is avoided; it may be thrown on the cars in the yard, and no unloading is required; here the expenses for loading are only 10 cents, and the hauling may be ten more. Thus a large quantity of fuel as well as time may be saved, because there is no occasion to wait for the cooling of the furnace. The fire may be applied in either way described above. A wagon-load may consist of two or more cords, which will require the cars to be 8 feet long

FIG. 152.

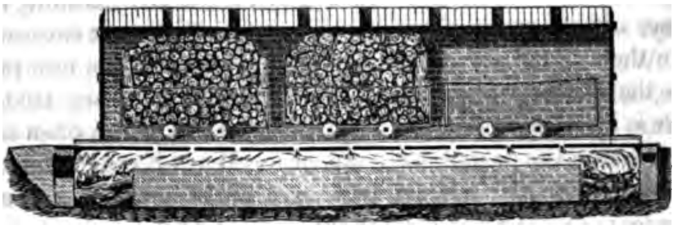
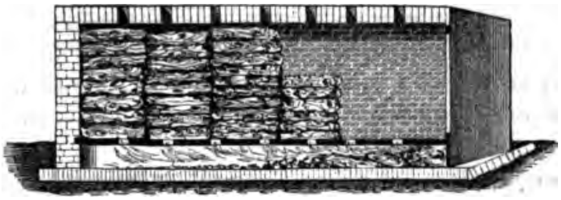


FIG. 153.



by 4 feet wide, and 8 feet high. Two or three tracks for cars may also be laid in one oven. Thus to dry a cord of wood cannot cost more than twenty-five or thirty cents, and it will be profitable where the air-dried wood costs only seventy-five cents.

Charcoal.—In most of the smelting operations, particularly those where the fuel is brought into immediate contact with the ore, the wood must be charred; that is, all the volatile substances must be driven off, and carbon, mixed with ashes, only will remain. The object of this operation is not so much to drive off all the moisture, as to decompose the woody fibre and expel hydrogen. Hydrogen is a powerful reviver of metals, reducing oxides rapidly; in many cases, such as those of smelting iron and copper, it brings substances in contact with the metal which deteriorate its quality. The methods by which charring is performed are various. We shall describe only those used in this country and elsewhere, which are really useful to the metallurgist: but, before entering upon this task, we will point to some general facts in charring, and the properties of the charcoal.

Properties of Charcoal.—If the various kinds of wood are charred under the same circumstances, that is, by the same means and at the same temperature, we may obtain charcoal of various qualities; for each kind of wood, as well as its different parts, and the amount of moisture it contains, will cause a variety in the quality. All these varieties may be brought to a uniform quality by proper treatment. We generally distinguish soft coal and hard coal, according to the kind of wood from which it is made; this distinction is more or less imperfect, for we may obtain a strong coal from pine wood, and a very friable, soft coal from hickory. A distinction in the quality of the coal is necessary, but that ought to depend on the coal itself, not on the wood from which it is made. We obtain, then, all other things being equal, brown or red coal,—that is, wood imperfectly charred,—and black coal; the latter in a great variety of forms, such as spongy, soft, and hard coal. The solid black charcoal consists chiefly of pure carbon, some per centage of ashes, and often a little hydrogen. Red coal is composed of about seventy-five parts of carbon and twenty-five parts of water, that is, the elements of water, oxygen and hydrogen. It still contains half the quantity of water which was in the kiln-dried wood, which consisted, namely, of 50 parts of carbon and 50 parts of the elements of water. The process of making red coal is therefore half-way between black coal and kiln-dried wood.

In delicate metallurgical operations, such as making steel, it is of some consequence to know the kind, and the quantity of the ashes in the coal. If we know the amount of ashes in air-dried wood, we find that of the coal by multiplying that amount 5 times; for in a well-conducted charring operation we obtain ⅕ of the weight of air-dried wood in hard black charcoal, ¼ of the kiln-dried wood, and ½ of the red coal. The quantity of ashes in black charcoal made of linde wood was found to be 3·55 per cent., that of ash 2·27, of pine 1·38, and oak ·75; these quantities may be rather low, but they afford a comparative estimate. Coal which has been charred under such disadvantages that half the carbon is burned away, of course contains twice, and in many cases three times as much ashes as these numbers indicate. Fine coal, or the small coal about a pit, generally contains a large quantity of ashes, because much of the carbon has been destroyed; for these reasons such coal, or dust—braise, as it is called—is heavy, burns very slow, and is used chiefly in the fires of forges.

Absorption of Water.—Charcoal, particularly when fresh, absorbs moisture and air with great rapidity; this absorption is frequently so violent as to cause the fresh coal to ignite, in consequence of the heat liberated from the condensed gas in the pores. Fresh coal may absorb, within the first twenty-four hours after its charring and cooling, from 1 per cent. to 20 per cent. of its weight of water and air. By experiments, it was found that hard coal absorbed within the first twenty-four hours of water only, as follows: beech coal, ·8 per cent.; ash, 4·06; maple, 4·8; chestnut, 6·06; pine, 8·2; poplar, 8·5; and soft Italian poplar, 16·3 per cent. On an average, we may assume that fresh coal absorbs about 4 per cent. of water the first day, and about a half per cent. every week for the next six months, after which the absorption is slow; this refers to coal protected by a water-tight roof. Charcoal contains from 4 to 20 per cent. of moisture, according to its age; beyond 20 per cent. it hardly rises, when kept in dry storehouses. Fresh and good charcoal may be considered to consist of 97 parts of carbon, and 3 parts of ashes; coal as commonly used, which has been stored for 2 or 3 months, contains 85 parts of carbon, 12 parts of water, and 3 of ashes. We must here remember that the water is hygroscopic, and absorbs heat; these 12 parts will consume nearly two parts of carbon for evaporation. Red coal does not absorb water so rapidly as black coal, particularly soft coal; still it has been found that after a storage of four weeks it had absorbed 10 per cent. of moisture. When red coal, therefore, consists of 74 parts of carbon, 24·5 parts of hydrogen and oxygen, and 1·5 parts of ashes, coal which has been prepared for one month consists of 66·5 carbon, 22 of the elements of water, 10 water, and 1·5 ashes. Hard coal and that having the least ashes will absorb the least amount of water, and will require the longest time for it. We observe here of how much importance it is to produce a firm strong coal, and to use wood which contains the least ashes.

Combustibility.—Firm, hard, shingling black coal is ignited with difficulty, no matter of what kind of wood it is made. The highest heat in the process of charring, with the perfect exclusion of moisture and atmospheric air, forms the hardest coal. On the contrary, low heat, and the presence of vapors or air, are the causes of soft, friable, and extremely combustible coal. Coal of rotten wood, or deadened wood, is, of all kinds, the most combustible, and often ignites spontaneously. Next to this in combustibility is that coal which has been produced by the distillation of soft wood, such as branches of willow and poplar, at a low heat in iron retorts. When such coal is freshly prepared and powdered, it frequently ignites without any apparent cause. Fresh red coal is easily kindled and very inflammable; but it does not ignite by the mere absorption of air and water. In all metallurgical operations we need chiefly hard, strong coal; those cases where soft, friable coal is required are few, and may be supplied by the waste coal which is always more or less abundant in any colliery. The necessity of producing hard coal is the more apparent when we consider that it absorbs less moisture in the same time, and retains its form better, than soft coal; it is attended also with less waste in the kiln and the coal-houses. For these reasons, the arrangements for charring wood must be such as to produce that coal which is the most compact and most incombustible; and as a high degree of heat, with the absence of moisture and air, are the most important requisites in making it, the operation must be so conducted as to secure them.

Quantity of Heat in Charcoal.—In former pages, we have spoken of this subject, and merely add here, that, when the quantity of heat in fresh charcoal is 97 parts in the 100, it cannot exceed 84 after it has been exposed for one month to the air; or, if the loss of heat caused by the evaporation of moisture and gas is considered, it cannot be more than 80 parts. We hence perceive the necessity of changing the coal charges to a furnace, in case fresh or old coal is used, and the propriety of using coal of nearly the same age, if regular work is to be expected. In addition, the necessity of bringing coal under a shelter as soon as possible is manifest. The specific gravity of the coal determines the quantity of heat in a single measure of it; this extends to the various kinds, provided they have been charred on the same principles; but the gravity is estimated on fresh coal which has not been exposed to the influence of the atmosphere. We may depend, in some degree, on the quality of the wood for this estimate, as shown in page 330; still it is clear that the mode of manufacturing the coal has an important influence on this result. Wood in charring shrinks greatly, some kinds more than others; this shrinkage also depends on the degree of heat and the mode of charring. Under the same circumstances, soft wood shrinks more than hard, and wood from old trees more than that from young trees and saplings. Pine shrinks the most, beech less, and oak and hickory the least of all. The specific gravity of the charcoal, therefore, cannot be estimated by that of the wood of which it is made. When the quantity of heat in a volume of oak wood is 28, that in the charcoal made of it is 15; and when the specific heat of pine wood is 19, that of its coal is 17; this shows how much more the coal of pine diminishes in volume while charring, than that of oak. If the shrinkage was the same in all cases, the quantity of heat in a volume of charcoal would be exactly one half that the air-dried wood; if it is more than one half of the shrinkage is in proportion.

Quantity of Coal.—A prime object in charring wood must be to obtain as much coal from it as possible. The value of coal is estimated by weight, and if other considerations have no influence on the charring, the aim of the collier must be to obtain the utmost weight. In all cases, we assume that perfectly air-dried wood is charred. A great difference is found in the quantity of coal, when charred slowly, or rapidly, as the following table shows:

100 parts of	Rapidly charred,				Slowly Charred.			
Young oak,	16·39	coal,	·15	ash.	25·45	coal,	·15	ash.
Old oak,	15·80	"	·11	"	25·60	"	·11	"
Young beech,	14·50	"	·37	"	25·50	"	·37	"
Old beech,	13·75	"	·4	"	25·75	"	·4	"
Young pine,	15·40	"	·12	"	25·95	"	·12	"
Rye straw,	13·10	"	·3	"	24·30	"	·3	"

We observe here, that in all cases the quantity of coal may be uniformly 25 per cent. of the weight of the air-dried wood; in the operation on an extensive scale, it is generally 20 per cent. The cause of this variation is plain. When air-dried wood is exposed to heat, this should be at first so low as merely to expel all the water,—that is, a boiling heat. If the temperature is higher, and a part of the wood or coal becomes red hot, while water remains in other parts, the hot vapors are decomposed on the hot coal and form carbonic acid and carburetted hydrogen; and the heat cannot be raised sufficiently high to form a strong coal: therefore that which is wanting must be obtained by burning a part of the carbon which would otherwise remain in the charcoal. The charring operation must be so conducted as to expel all the hygroscopic water at the lowest possible degree of heat. This heat should not decompose the woody fibre, or exceed 270°. When the water is entirely expelled, the heat may be raised so as to liberate hydrogen, which will combine, at first, with the oxygen of the wood, and also afford heat; but, in order to expel all the hydrogen, because there is more than can be absorbed by the oxygen which is present, the heat must be raised still higher, by which some of the carbon is carried off with the hydrogen. At this period, some fresh air should be admitted, which will burn the carburetted hydrogen compounds, and advance the heat to that high degree required for the formation of strong coal. The admission of air must be, of course, limited to the neutralization of the hydrogen compounds, and it must be conducted throughout the mass of hot coal, or an inevitable loss of free carbon will ensue. It is not absolutely necessary to introduce fresh air at any stage of the process. The mere application of external heat is sufficient to produce good coal; but, as this requires the use of additional fuel, and the combustible hydrogen compounds are of no actual value to the metallurgist, it is found more profitable to use the volatile combustibles for generating it. This is the simple theory of charring; it shows at once the objects which the collier must keep in view. A strong heat, at first, and a moist hearth, will inevitably cause a loss of carbon and produce a soft coal, because there will not be sufficient heat to form hard coal. Coal made in an iron retort must be soft and expensive, in consequence of a deficiency of heat and the necessity of additional fuel. The application of retorts, for the sake of distilling wood, is inadmissible in our case, because the additional expenses are not repaid by the products of the distillation, and the coal is invariably of an inferior quality. The metallurgist is therefore confined to those operations in which the volatile substances are used as fuel to generate the necessary heat.

Charring.—Since we are limited in the production of charcoal to that process in which atmospheric air is required, it must be the object so to direct the current of air that it shall first touch the wood, and not reach the hot coal until all its oxygen is consumed. If we observe this rule, the process is extremely simple in whatever form we may execute it. It may be practically impossible to arrive at perfection; still, by having this rule before our minds, we never can fail of tolerable success. The charring of wood may be divided into two distinct processes; the one which is conducted under covers either movable or permanent,—the other in pits and ovens. Both have their advantages and disadvantages; and it is chiefly considerations of economy and expediency that determine which of the two shall be adopted.

Charring under Movable Cover.—The most simple form of this operation is in pits or heaps. We shall not allude to any imperfect methods used elsewhere, and therefore confine our remarks to those in use here, and those which possibly may be employed to advantage. The first thing to be done for charring in a pit, is to select a spot nearly or quite level, nearest to the stores of cord wood, that the transportation of it may be low, and the wagons for the hauling of coal may easily approach. Above all things, the place where the hearth is to be, must be dry, and free from rock. When no level spot can be found convenient, one from 40 to 50 feet in diameter, is made on a hill-side. All stones and gravel must be removed, and the ground must be dry and fine, not sandy or loamy; a soil somewhat gritty is the best in which to locate a hearth. When stones or gravel cannot be avoided in selecting a spot, the ground must be dug up for one or two feet, and riddled to remove all coarse matter. If the ground is too rocky or damp, a layer of brushwood one or two feet in depth is spread over it, and upon this a layer of soil of one foot in thickness is thrown, which forms the hearth. If the ground is too sandy, it may be mixed with dry loam sufficient to make it slightly adhesive.

Pure sand would be in fact the best material for a cover, but it is liable to leak in between the wood and coal, and make it difficult to keep the pit close. The best cover is formed from the earth where one or two brands have been made, and the dust is blackened and mixed to a certain extent with fine charcoal. Around the circumference of the hearth the wood is first piled so as to form a circular wall, as represented in fig. 154. All the wood required for one brand is hauled at once to the hearth; this may be 25 or 50 cords. One side of this wall is open for the entrance of wagons or sleds, and the interior free to admit of turning a wagon. The lightest kind of wood is first hauled to the pit, to be used at the last for covering the heap. The heavy billets, or those split of heavy timber, are afterwards hauled and form the interior of the pit. When all the wood requisite for one brand is hauled, the collier erects in the centre of the hearth, which may be made slightly convex, three sapling posts, four inches in thickness, and of the height which the heap is to be; this is generally from 12 to 15 feet, most commonly 12 feet. These posts, as shown in fig. 155, are about one foot apart, and are held in their position by short braces bound together with switches. At the bottom, between these posts, which form a kind of chimney, some dry inflammable substance is deposited, such as brands from former fires, dry chips, or charcoal; in fact, this chimney may be filled at least half its height or nearly to the top with

FIG. 154.

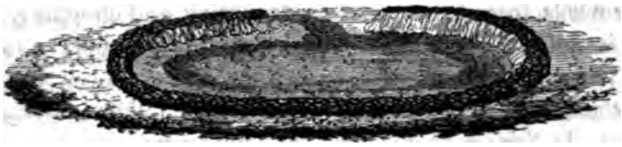
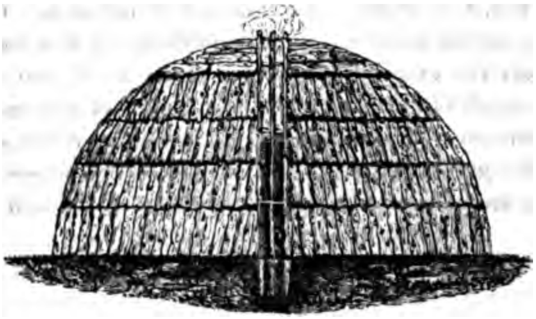


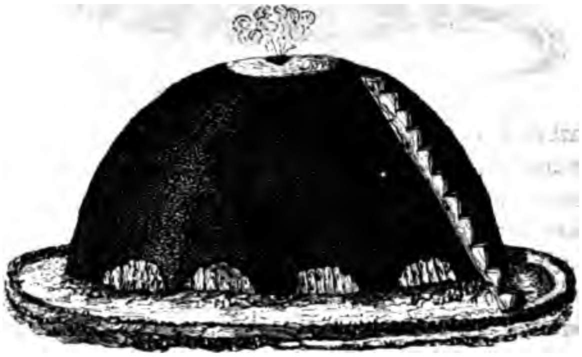
FIG. 155.



such substances. Around this centre the billets of wood are erected—the heaviest first, with the buts lowermost—so as to form a gradual slope towards the circumference.

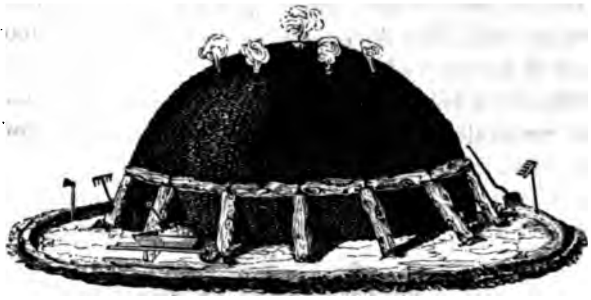
One of the most important objects in setting a pit is to have as few and as small spaces as possible, and when these exist, to fill them with small branches and short billets of wood. The collier needs therefore an axe, for trimming and chopping. The wood is not often so cleanly trimmed by the choppers as to form close joints. When sufficient coal-dust is at hand, it is an excellent plan to fill the crevices between the billets entirely with small coal; this increases the yield considerably, and affords a coal superior to that derived from the open setting. A little more labor is thus caused, but it pays well in the course of time. In all cases the round, or bark side of the billet is turned outwards, and the split sides towards the centre. In setting the second tier of wood, particular attention must be paid to the joints at the ends of the billets, because there it is most difficult to prevent spaces. In case three tiers of wood are set, the upper one is more inclined than the lower, so as to secure the adhesion of the dust. When, in this manner, all the wood is properly distributed, and a round heap is formed, all the exterior spaces are nicely filled, and thatched with chips, small branches, small wood, brands or charcoal. The whole is then covered by a layer of damp leaves, which are gathered from the ground near the pit. These leaves, which serve to prevent the dropping in of dust, or earthy cover, are now covered by dust. A small circle on the top is left uncovered for the sake of preventing the dropping of dust into the centre. The pit assumes by this time the form represented in fig. 156. At first

FIG. 156.



only a slight layer of dust is put on, merely to cover and hold the leaves down, so that a gust of wind may not blow them off. Fire is now applied by dropping some burning coals from the top into the centre, thus kindling the combustibles at the very bottom and centre of the heap. The firing should be done in the morning, and when neither wind nor storm is apprehended. In order not to disturb the covering of the heap, steps are made of a six inch sapling, or a slab, on which to ascend to the top. The fire, thus applied, must be carefully watched that it may continue to burn slowly: it is nourished by air drawn in through several places which are left uncovered at the bottom of the heap. When the fire within is well established, which usually takes some five or six hours, the centre is entirely filled with brands; but no cover is yet put on the top; some leaves only are thrown over to prevent a strong draught. The collier proceeds now to secure the earth all around by adding still more; so that within the first twenty-four hours the heap is entirely covered with the dust from two to three inches in thickness. The pit now has assumed the form represented in fig. 157. In the central part of the top the cover is thin, so that smoke, or, in fact, only steam and hot invisible gases, may escape. When the heap is steep, so that the cover will not adhere well, some billets of wood are set around it. At the bottom are still some small air-holes, which are not closed until the pit begins to sink or settle at the top. When the operation is well conducted, the top settles after sixty hours' firing; if it settles sooner, there is something wrong. While the settling is going on, the earth becomes moist, and is easily flattened down by a shovel; but this must be done with caution. If the cover is too close, as it is particularly liable to become, when it consists of green dust, it is in danger of being

FIG. 157.



partially blown off by explosions within. During the first two days it is therefore not advisable to have the cover too close, or too heavy. The proper covering can be determined only by experience, for it depends much on the kind of earth of which it is made. On the other hand, a thin cover requires always more attention than a heavy one; and it is particularly unsafe in squally weather, and under the care of inexperienced persons. Most of these difficulties may be avoided by making a heavy cover at the start, with a free vent at the top, and means for a liberal access of fresh air at the foot of the heap. An active circulation of air will prevent all those accidents, which often cause a considerable loss of wood.

When the top begins to settle, some dust is thrown into the centre of it, so as to draw the fire more to the exterior; and as it continues to settle, dust is thrown on for at least two days longer to prevent a strong heat. During this period the greatest caution and watchfulness day and night must be exercised, particularly in stormy seasons, and with green or sandy earth for a cover. It will happen, in spite of all attention, that a pit settles irregularly, although it ought to settle uniformly from the centre towards the periphery. When the former occurs, it is regulated by increasing the covering at the low places and by diminishing it at the high spots, so as to draw the fire towards them. Should it happen, either in consequence of a new hearth, or from inattention, that a part of the pit burns hollow and threatens to sink suddenly, that portion must be opened quickly by removing the cover, and filled with charcoal, brands, or even charcoal dust if nothing else is at hand. Some colliers are in the habit of filling such places with fresh wood; this is useless, for such wood does not make coal,—at least not good coal;—and it is the cause of wasting that already formed—in fact, it injures the whole pit. It happens frequently that the centre burns down too deep, before the wood sinks; it is then also filled with coal, and kept full, until it sinks regularly and altogether, after which it is covered by dust.

In fair weather and under good management, the aspects of the pit change about the third day. The smoke then begins to be dry, and no cloud of vapors hovers over the apex, and the gases begin to smell of the products of the distillation. The pit may be now covered all over, and no air-hole left open. When the cover has been too thin, it is increased; all cracks and crevices are carefully stopped, and the pit driven on very slowly without vents to urge the fire. If all these things have been well done, the settling of the pit is uniform; it begins in the middle, and extends gradually towards the circumference. A pit assumes at this period the form shown in fig. 158, which is a section of one; the coal forms an inverted cone, and the fire draws from the centre gradually towards the edge of the heap. The smoke, or hot gases, escape always at the highest part, or at those places where the fire exists; from the other parts of the surface, which ought to be dead, none should issue. We observe here that the successful burning of the pit is influenced by the direction of the billets; for the fresh air which is drawn in at the foot will naturally follow this direction or pass through the spaces between the billets. When they are properly set, there is also the advantage of making the strongest and most coal. As remarked before, the leading object in charring wood must be to conduct the fresh air over the wood, and not over the hot coal. If we kindle one end of a bundle of sticks, and hold it so as to turn the flame downward, as shown in fig. 159, we do not obtain any coal; after the volatile substances are expelled the hot charred wood is rapidly consumed, and ashes only remain. Thus the hot gases generated in the burning coal pass through the wood, dry it too fast, and convert it into small disconnected fibres, as if crushed by a hammer; such wood of course cannot form any other than small coal, and very little of that. If we turn the flame of the fagot of wood upwards, as

Fig. 158

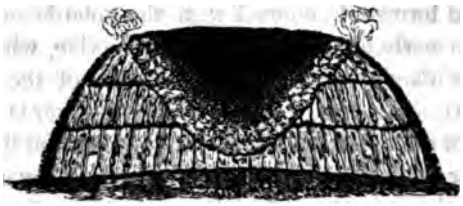


Fig. 159.

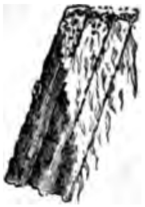
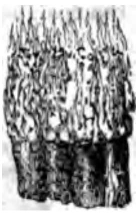


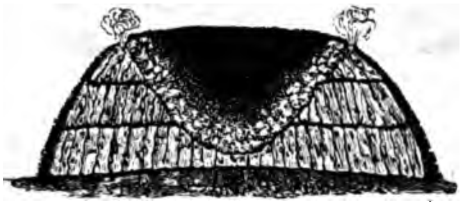
Fig. 160.



shown in fig. 160, the result is quite different; for the air, in passing through the spaces between the sticks, will absorb the moisture gradually and dry the wood slowly; on arriving at the flame, it will find sufficient carbureted hydrogen to combine with, and consequently will not absorb much carbon provided no excess of air is admitted, so as to furnish free oxygen. This mode will, however, not furnish the largest quantity of coal; for, if the coal above the flame is still red-hot, which of course cannot be prevented, the carbonic acid formed in contact with the volatile substances will absorb more carbon and form carbonic oxide, which is recognized by the blue color, at the extreme end of the flame. This blue flame is often observed at pits when the cover is too light, and when there is too much heat in the coal; it invariably causes great loss, however good the coal may be. A strong cover, to keep the fire down, is the only means of preventing these occurrences.

The perfectly vertical position of the billets, with the fire at the top, is therefore the most perfect manner of setting a pit, provided the access of air can be so regulated that only a sufficient quantity is uniformly drawn in. We see now the necessity of a uniform and close floor for the hearth, and a uniform and close cover, so that no accidental vents may disturb the work. These particulars cannot often be observed in practice. To arrive, however, as near to perfection as possible, the billets are set inclined. In all cases, whether the billets are vertical, inclined, or horizontal, the progress of charring ought to be conducted as represented in fig. 161. For if, instead of an inverted cone, the coal assumes the form of a cylinder, or, what is worse still, that of a right cone, the flame will pass through the wood instead of through a part of the coal, and cause small and brittle coal. When the billets are vertical, and the fire descends, the strongest coal is formed; and when the fire ascends, the weakest coal. An inclination, such as has been described, forms a coal between the two.

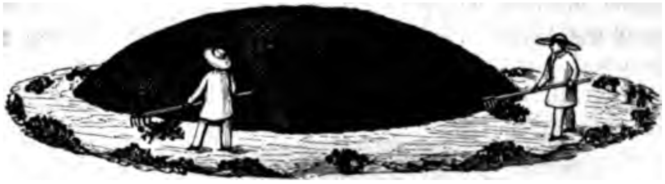
FIG. 161.



During four days, in good seasons, and in stormy weather from six to eight, a pit must be closely watched; after that time, the fire is well spread in the interior, and, as little air is required, all the air-holes around the base are well stopped; some vent-holes may be put below the natural vent, as shown in fig. 158, to accelerate the work; for all the wood is now well dried, and the charring may be pushed to completion as soon as possible. In four days more, all the wood will be charred; thus a pit may be burned in one week or ten days, unless in stormy or wet seasons, when it will require between ten days and three weeks. When the fire is drawn to the circumference, the heap is closely covered and left to cool slowly.

After the further lapse of twenty-four hours, the drawing of the coal is begun; and it should be at once hauled and put under the cover of the storehouses. The drawing proceeds slowly. From 200 to 300 bushels are taken during the first day from a fresh pit; this may be gradually increased so that a pit of 2000 or 2500 bushels will be drawn in a week. This operation is commenced at the circumference; a little dust is removed from a place, and about one bushel taken by means of a wooden rake; the earth is then carefully replaced to prevent the access of air to the interior of the pit, and another place is opened. A careless or too rapid drawing may set the pit on fire again, and cause a great loss of coal. When the process of charring has been well performed, the pit has the appearance represented in fig. 162. It shows a gently rounded mound of about half the height of the original pit, although it is somewhat higher when hard wood has been charred. An irregular, waving surface shows either bad work, or a bad hearth. The coal drawn is deposited in detached small piles, so that if one kindles—which frequently happens—the others may not be ignited. These detached heaps are covered by cold or damp dust, to prevent the access of air; the object being merely to cool the coal, not to wet it. Hot dry coal, when free from fire,

FIG. 162.



absorbs air so readily that it kindles spontaneously; cold coal absorbs it also, but not so fast as to cause ignition. When the coal has been drawn and exposed to cooling for a couple of hours, it is assorted; brands, or pieces of wood partly charred, are not at once loaded, because they are the most liable to spontaneous combustion. They are retained for some days, and then sent to the smelt-works; or, if they are not used in the furnaces, they are retained by the colliers, and charred at the next burning, by being placed in the spaces between the billets. The best coals are generally found about one foot high from the floor, and at an equal distance from the roof; in the centre the coal is weak. This shows that large pits are more favorable for the production of good coal than small ones, and that the fire in the centre should work as slowly as possible; for it is the rapid charring which injures the coal in the middle of the pit. Most of the brands are generally found near the floor, and amount to one-twelfth of the coal in large, and to one-sixth in small pits, where the work has been good. A larger amount of brands shows bad work. The coal should be assorted at the pit into coarse or furnace coal, small or forge coal, and brands, and the collier paid according to these qualities—receiving a higher price for furnace coal, a lower for small coal, and the lowest for brands. Very small coal, such as cannot be used in the forge, is retained by the collier; with it he forms the floor and fills and covers other pits.

The quantity of coal thus obtained, from a cord of wood, varies from twenty-five to forty-five bushels. If the wood is cut and corded during the winter, and charred in summer, a skilful collier will obtain, on an average, forty bushels of good coal from a cord. The amount of this yield is modified by various circumstances. If the wood is badly chopped, or ill-trimmed and short, or the measure too small, it will not yield well. Green wood yields badly, and causes weak coal. Coal charred in winter or stormy weather is always poor, and the quantity is small. Green dust, or that which cakes, also causes weak and little coal; light and porous dust will often be the cause of good coal, although little of it. The best dust is that which has been used for a few brands, and is well mixed with small coal. A heat which is too strong at the start causes weak and small coal; and, if continued throughout the operation, always results in little, and often bad coal. Young wood makes a stronger coal and more of it than old wood, provided proper care is taken in charring. Careless workmen invariably make little coal, and if inexperienced also, they make weak coal.

It may be more convenient to purchase coal by measure than by weight, but this certainly is not the most correct method, neither is it the best for either seller or buyer. Hard, strong coal is, in all smelting operations, of greater value than soft coal, and in consequence of buying coal by the measure, we tempt colliers to make soft coal and much of it; on the other hand, as there is but little difference in weight, whether strong or weak coal is made, it is certainly more advantageous to the smelter that it should be strong coal. In all cases of charring, no matter in what form, or by what means, a well conducted operation will furnish from 20 pounds to 23 pounds of charcoal from 100 pounds of seasoned wood. The coal may be weak or strong, not more nor less, however, ought to be produced. Slow charring and low heat, will produce the highest number, but it will be weak coal; a lively heat well conducted, will furnish the lowest, but make a strong coal. This determines which mode of charring is the most profitable to the smelter. With a well conducted operation in a pit, like the one above described, containing at least 50 cords of wood, the yield ought to be in the proportion shown in the following table, for air-dried wood:

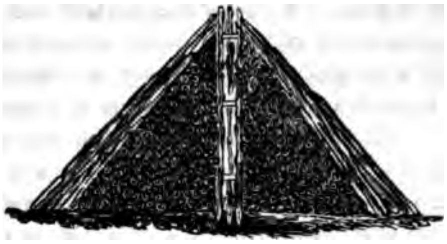
Kind of wood.	Yield by weight.	Yield by measure.
Oak,	23 per cent.	74 per cent.
Beech,	22 "	73 "
Pine,	25 "	63 "

A cord of 128 cubic feet of oak ought to furnish 64 bushels of 2,600 cubic inches each. Pine wood must yield 54 bushels of the same size. This measure is actually reached by good colliers, although not by the average of workmen. The best means of obtaining a large yield and good coal, is by using large pits; there is little difficulty in making 50 bushels of coal in a pit containing 200 cords of pine wood, or if it contains hard wood, 60 bushels; and the coal may be equally as strong as the yield is good.

We have been thus particular with this mode of charring, because it is the one most generally used in this country, and perhaps the best; still there are some modifications, which may tend to cheapen the process in particular cases; if these are pointed out, any one can judge readily how far they are advantageous.

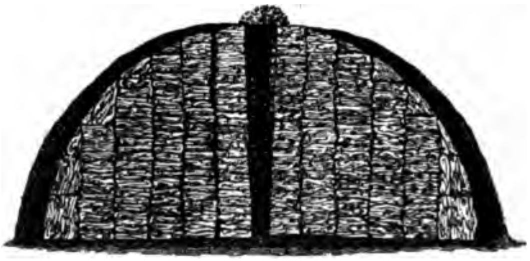
A method of charring generally followed in Norway, is represented in fig. 163. The centre poles are here erected as before mentioned, but the wood around them is laid flat and covered outside by slabs, to obtain the slope. This method can be adopted only near saw-mills, because it is only there, that slabs can be obtained. The covering may be made, equally as well, with billets; but then this affords no other advantage than the saving of a little labor in setting the wood. Wood laid horizontally never does, nor can, afford as strong coal as when placed upright; and where strong coal is required for blast furnaces, this mode of charring will not furnish the best. For forges and similar operations, where weak coal is equally as good, and preferable to hard coal, this mode of charring affords some advantages.

FIG 163.



Another method which is practised to some extent in southern Europe, is represented in fig. 164. A heap, consisting of about 60 cords of wood, is erected in a form similar to that described in fig. 155; but the wood is laid almost horizontal, or inclined gently towards the periphery of the heap. The wood used in this instance, is in the form of round sticks, from seven to eight feet long, and as heavy as two men can carry. It is deposited around the chimney. The heap is well dressed with a layer of leaves or small coal, and then a heavy cover of very light dust,

FIG. 164

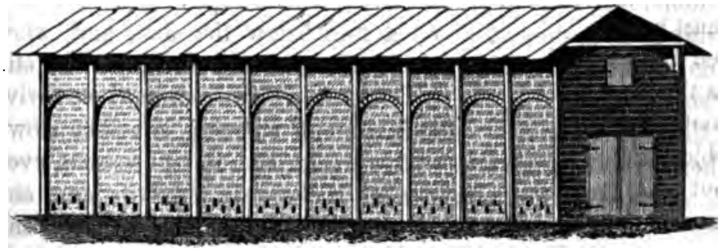


consisting chiefly of coal dust, is thrown over it at once. This cover is two feet thick at the base, and gradually diminishes to six inches near the top; it is held by props and slabs around the heap, to prevent its sliding down. The chimney, for two-thirds of its height, is filled with dry, inflammable chips, or brands, and, upon this, burning coal is deposited, to kindle it and produce a lively fire. The difference between this method and the common one is, that here no fresh air gains access, excepting that which is derived from the ground and through the heavy covering. The fire in the centre is fed by charcoal as it burns down, and the chimney is constantly kept full. For this reason the chimney is wider than in other cases,—being at the top three feet in diameter, and at the base two feet. The burning coal is generally heaped upon the chimney, so as to form a cone at the top. As the heat for drying the wood is altogether derived from the burning charcoal in its centre, it is from three to four, and often five days, before the watery vapors disappear. This is the time for explosions, and the cover on the top is therefore somewhat removed, to allow a free vent for the rapidly generating and explosive gases, which require about twenty-four hours to escape. When this danger is passed, the top is covered again by a heavy layer of dust, twelve or fifteen inches thick, and a series of vent-holes are opened, by means of a shovel handle or a pointed pole. The first series of vents is near the top, and when a blue smoke is visible from them, they are stopped up and the dust beaten down, so as to prevent any further escape of gas. Another series is now opened about a foot below the first, and when blue smoke issues from these, they are stopped, and a row still lower down opened. In this manner we proceed, until we arrive at the foot of the heap. This mode of charring is rather slow; a heap requires from four to five weeks, and, in bad seasons, even a longer time, before all the wood is charred; but little labor and attention is needed when the fire is once started; the pit is not affected by storms, and furnishes good coal and a great deal of it. Inexperienced hands make better coal in this way than by any other mode.

The other methods of charring, such as in mounds, or in square, or oblong heaps, wherein wood is laid, or piled to a limited height, afford no advantages over those which have been described above, either in the quantity or quality of coal, which is generally of an inferior kind, or in the saving of labor. Time may be saved; but if this is to be accomplished on account of wood, it may be quite as well done in a small round pit. For these reasons we omit to speak of the other methods of charring under a movable cover. In all cases, whatever the form of the heap may be, the rule is, to form as little surface of it as possible. The form of a globe would be the most perfect for a charring heap, if it could be adopted, but as that cannot be done, the half globe is preferable to all others. There is one circumstance not favorable to large heaps or round pits—it is the necessity of storing coal extensively, because the charring can be performed only during the dry and pleasant seasons of the year.

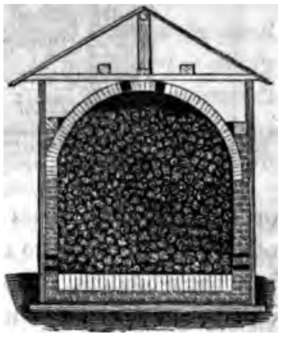
Charring in Ovens.—In order to avoid keeping large stores of charcoal, and to obtain it dry and fresh,—to save labor in particular cases,—and to be less subject to the faults of inferior workmen, the charring in ovens or kilns is resorted to. Generally speaking, the advantages of ovens over pits, are not so great as is often supposed; and, as a rule, we may assert that all charcoal made under an immovable cover is not so strong as that made under a movable one. The only real advantage of the oven arises from its being less subject to the changes of the atmosphere, than the pit. The best form of a char-oven, and that which is most generally in use in this country, is represented in fig. 165. It is a long prismatic oven, the floor and rough walls of which are of common red brick, the interior of the side walls and the arched roof are lined with fire-brick. Such an oven 40 feet long, 15 feet wide, and 15 feet high, in the clear, will contain about 60 cords of wood. In fig. 166, a vertical section of this oven is shown. The binding of the kiln, which is here represented to be of wood, is seen more distinctly than in the engraving above. The roof is a necessary appendage; it protects the walls against moisture, which is particularly hurtful to the arch, and consequently to the coal.

FIG. 165.



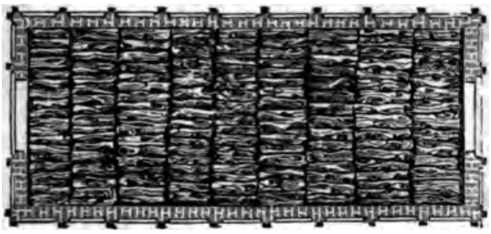
The floor is well paved with hard common bricks, set edgeways, below these another layer of bricks or stones is laid upon a plank floor, which rests upon the cross timbers or binders. The mode of binding requires no further explanation; it may be added, however, that it is necessary to use young and sound timber for this purpose. The bricks are laid in fire-clay mortar, in preference to lime mortar, because the latter is soon destroyed by the acetic acid, which is liberated by the wood. This clay mortar ought not to be too fat, and it is advisable to use a little salt in it; this causes it to dry harder, and bind stronger. In laying the bricks, particular care must be taken to fill the joints perfectly with mortar, that no leakage may take place through the walls, which for better security may be painted on the outside with a mixture of coal tar and clay. This forms an extremely hard and strong cover, which is not at all liable to break. The clay is dissolved in water, and put first over the brick wall, like a wash, then the tar is painted on before it has become perfectly dry.

Fig. 166.



In order to secure strength and close joints, the walls must be at least 14 inches thick, consisting of a lining of fire-brick 5 inches in width, and red brick 9 inches. Both the lining and rough wall must be well bound together by occasional binders, which unite the red and the fire-brick. The arch may be of 5 inch fire-brick; but as the span is wide, there is no harm done in making a 10 inch roof. Many kilns are built of red bricks only; to this there is no objection; they answer equally as well as if lined with fire-brick; but then, in such case, the common bricks ought to be made of a kind of loam which will stand fire well. If this loam contains too much iron and lime, the bricks of the roof will soon shrink and drop. It is, therefore, necessary to test the red bricks in a strong fire before a kiln is built of them, at least those used for the lining and roof; if they resist a high red heat without melting, they may be considered good for this purpose. When a little more expense is no consideration, it is a good plan to increase the strength of the side walls by bracing them with pillars, as shown in fig. 167, which is the plan of a kiln. At each end there is an iron door of six feet in width and eight feet in height, so that a railroad car may be run into the oven, loaded with wood, or to take off the coal. All the kilns in use resemble the above more

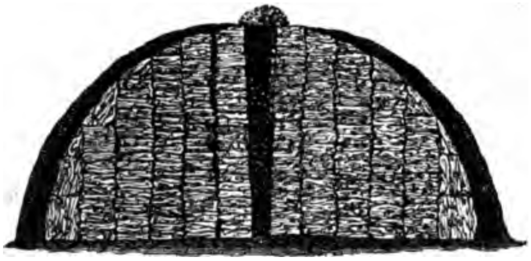
FIG. 167.



or less; in some cases the roof is less steep, to gain room; in others the binders are made of cast-iron uprights, and wrought-iron cross-binders. In some, the gases are drawn off by a series of vents in the top of the roof; in others, by vents at both ends; in which case the vent holes are provided with iron doors, as shown in fig. 165. In all cases a series of draft holes is provided all around the foot of the kiln; and by stopping one and opening another, the access of air, and consequently the fire, is regulated. These apertures are of the size of a brick, ten inches by two and a half in height, so that a brick may fill one.

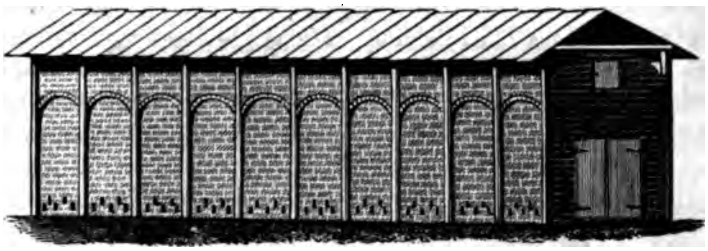
The operation of charring is extremely simple in these kilns. The wood is laid flat on the floor and piled up to the roof, as shown in figs. 168 and 169. It may also be set upright, but as

FIG. 168.



this is more laborious it is not generally done; still there is no doubt that the coal is stronger from the billets which are standing, than from those which are laid flat. The fire is applied in various ways; some prefer putting it at the top, in the middle of the arch, and drawing it gently downwards; others form a channel of brands, or of dry chips, or of charcoal through the middle of the floor, and apply fire at both ends; and others again apply fire at the draught holes around the foot of the oven. Of all these plans the latter is the most objectionable, for it causes necessarily a waste of wood, and makes weak coal. With a channel through the middle, firing at both ends is better, but the best plan is firing on the top, particularly in wide ovens. In all cases the wood that is charred ought to be well seasoned; for wet or green wood yields 20 per cent. less coal than dry. Or, in case seasoned wood cannot be had, the charring ought to be conducted with extreme slowness; the fire should be applied at the top, and fed by coal or brands. A liberal supply of fresh air should be allowed to pass through the interior. Charring green or wet wood is, in no case, profitable; and in order to obtain the best yield and greatest amount of coal, the wood, as it is delivered at the yard, should be stored under cover and protected against rain. One heat may be performed in a week, so that an oven may be reckoned to produce from 1200 to 1500 bushels of coal in that time; but generally two and three weeks are occupied in charging, charring and discharging a kiln. It is not difficult to conduct the charring in these ovens, when the walls are perfectly air-tight; but if they are not so, it is rather troublesome and causes considerable loss of wood. When the watery vapors at the top of the kiln or at the vents cease, and no smoke of any kind issues, but a whitish blue gas makes its appearance,—which is often the case at the third day after fire is applied, although more generally on the fourth or fifth day,—the vents are stopped up; and as the fire becomes visible at the apertures near the base, these are also successively stopped. When we are satisfied that the heat has spread throughout the interior, all the openings are well stopped by bricks and secured by a layer of fine sand, to prevent the access of air. Two days, or at the

Fig. 169.



most four days of cooling are sufficient to deaden the coal so far as to make it ready for drawing.

The above described kilns are the best for the use of the manufacturer of metals, and there is no occasion to attempt to make improvements on the principles involved in their construction; but, as it may happen that, under peculiar circumstances, a light coal and an advantageous use of the products of distillation may be made, we insert in fig. 170 a representation of a char oven, frequently used in Sweden for this purpose. It shows the section of a brick oven with a pointed arch, which is charged with wood in the usual manner. The oven is from 25 to 30 feet in width, 17 or 18 feet high, and equally as long; the arch is two feet thick, and the side walls still thicker. Two openings, or flues, A A, lead from a fire chamber or furnace, of which there is one on each end; these flues are about 15 inches square. Fig. 171 shows a vertical section in the opposite way. We observe here that the bottom is concave, while it is convex in fig. 170. The cast-iron pipes, B B, lead the gases from the oven, by means of a knee pipe, to a barrel in which wood-tar is gathered. Another pipe communicates with a system of wooden or iron condensing pipes which are conducted around the oven, and from these, those gases which do not condense pass off by a chimney.

Fig. 170.

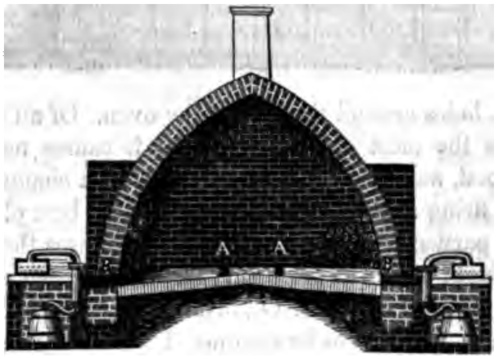
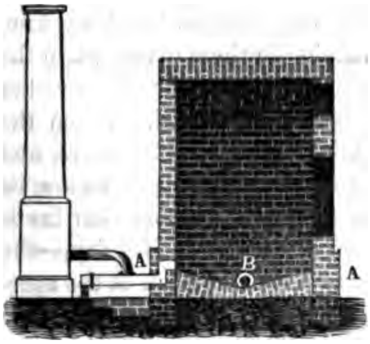


Fig. 171.

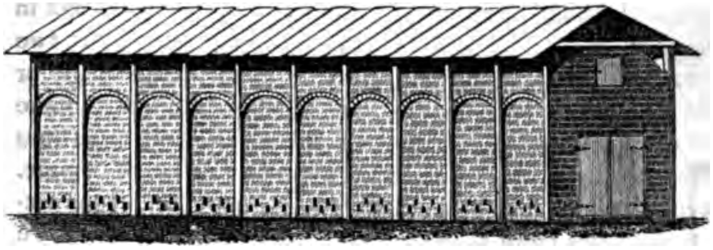


The manner in which this apparatus is put in operation is as follows: when the oven is charged with wood, through the doors C C, these are hermetically closed, so that no air can pass into nor go out of the oven except by the flues A A, and the pipes B B. The light wood has been laid near the bottom, which is well paved and smooth, and the heavy billets above. A fire of wood is now made in both furnaces A A; and it must be so conducted, that all the oxygen of the air is consumed in this fire-place although it has no grate to facilitate that object. The chimney causes a draught, and the heat in passing from the furnaces through the wood, converts it into charcoal without much loss of coal. The products of this distillation are deposited partly in the tar barrels and partly in the condensing apparatus.

This oven makes a good deal of coal, but it is very weak, and the extra fuel consumed amounts to one fifth of the wood charred. If, therefore, the products of distillation do not pay for this extra fuel and the loss sustained in consequence of the inferior coal, there is no advantage in using these furnaces.

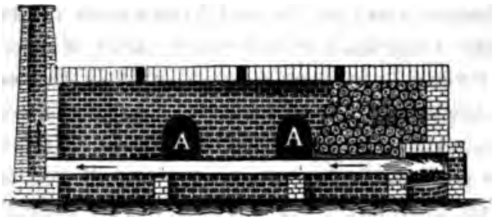
When we wish to obtain acetic acid,—tar cannot be of any use—for the manufacture of sugar of lead, or acetate of potash or lime, the better plan is to use the oven represented in fig. 172, with such alterations as will secure good coal. If a cast-iron pipe is laid over the bottom of the oven, as shown in fig. 173, we may succeed in making good coal and secure the valuable parts of the distillation. The manner of operation is, in such case, to charge the kiln as usual, and to make all apertures perfectly air-tight, with the exception of a wide flue which leads from near the bottom of the furnace to a condensing apparatus, which serves both for distillation and the absorption of the gases, and thence to the chimney. Thus the volatile substances only are conducted to the condensing apparatus, and the tar sinks to the bottom of the

Fig. 172.



furnace and serves as fuel, after all acetic acid is expelled. When this is accomplished, the flue leading the gas from the oven, and which, by the way, must be of brick, is stopped up, and the operation of charring conducted as usual, that is, by opening the apertures for the admission of air, as well as the vents. In case the heat within should be too high, so as to endanger the cast-iron pipe, in which of course no fire is any longer needed, a current of cold air may be admitted to pass through and cool it.

Fig. 173.



Cost of making Coal.—On examining the quantity and quality of charcoal obtained by either method of charring, we find that local circumstances determine which it is best to adopt. In the pit, or heap, we can obtain, with perfect regularity, 20 per cent. of coal from seasoned wood; the oven will not make more than 25 per cent., which yield may be reached by having a heavy cover and with slow charring in the pit. So far kiln and pit are nearly on an equality as to the amount of the yield, at least there is not more than 10 per cent. in favor of the kiln. The wages paid for charring in pits, where the wood is delivered, is from 1½ to 2 cents per bushel, and in ovens it is about ¾ to 1 cent, for the same quantity. If a cord of wood makes, on an average, 40 bushels in the pit, and 45 in the kiln, the amount of the kiln cannot be regarded as more than that of the pit, although the measure may be more, because the coal in the former is lighter than in the latter. The transport of the coal from the woods to the furnace yard causes a loss of 10 per cent, which is also in favor of the kiln. All the advantages of the kiln over the pit amount to 20 per cent., from which, the interest on the investment in ovens is to be deducted. All the other circumstances are equal, for the wood must be as well stored under sheds as the coal, and there is no advantage in favor of either. If 40 bushels is the capacity of the pit, and 50 bushels of the kiln, we gain from the cord of wood by using the latter, 10 bushels of charcoal. If the price of a cord of wood is 40 cents, which may be considered the lowest, and which prevails only in the Western and Southern states; one bushel of charcoal made in the pit will cost 2¾ cents or say 3 cents, in the woods; and in the furnace yard exclusive of hauling, 3¾ cents, including loss; or, the coal from a cord of wood will cost $1,41 cents. Coal made from the same kind of wood, in the kiln, will cost 90 cents per cord of wood, that is, the wood costs 40 cents for chopping and lease, and the charring 50 cents; here are 51 cents gain over the pit, per cord, of wood in the furnace yard; or near 33 per cent. in favor of the oven. When the wood is in the yard, the coal of the pit will cost but 3⅓ cents per bushel, or $1,30 per cord of wood, which reduces somewhat the advantages of the oven. But from this it is evident that when the wood is at the furnace, the oven is decidedly preferable to the pit. If the wood, or the charcoal is to be hauled from a distance, it will depend on that distance, and the means of transport, whether it is more profitable to char in ovens than in pits. At the lowest price of wood, the oven is 50 cents more profitable per cord than the pit, and as the coal of 5 cords of wood, say 4 cords, is equal to one cord of wood in weight, these 50 cents taken 4 times and divided by 3, or 66 cents, is the price, which may be paid for hauling 1 cord, instead of the coal made of it. If the cartage of wood costs more than this there is no advantage in bringing it to the yard. When a cord of wood costs more than 40 cents, it is still more advantageous to use the oven. If a cord of wood costs $2, and the advantages exclusive of labor are 20 per cent., which makes 40 cents on a cord, and the difference in wages for charring on a cord is 30 cents, the price paid, for hauling wood, instead of coal, to the yard, may be $\frac{40 + 30 \times 4}{3} = 93$ cents on the cord, before the methods become equally beneficial. If these favorable circumstances in carting wood can be secured the oven has its advantages, but not otherwise.

Charcoal when taken to the yard should be stored under sheds to preserve it from getting wet. It is asserted, and not without reason, that damp coal is to be preferred to that which is dry and fresh; this latter, therefore, is not used as it comes from the pits, whilst that which comes from the ovens is used in its dryest state. The assertion that old coal, or damp coal is better than that which is fresh, relates chiefly to such as is used in forges, and lead and copper smelting furnaces, rather than to iron furnaces. There, is however, some foundation for it with regard to blast furnaces. It is, nevertheless, certainly untrue that old coal gives out more heat than that which is fresh; its superiority, however, over the fresh coal, may be thus explained:—The charcoal brought in from a pit, cannot be uniformly dry; one load is more damp than another; nor is coal from different collieries, although made of the same wood, of equal quality. In charging the furnace, therefore, with such coal, the dry will raise the heat higher up in the stack; and as it is a nice point in all blast furnace operations to keep it at a certain height, the change thus caused by dry coal, even if favorable, is a disagreeable one. If, in addition, after one, two or more charges of dry coal, a damp charge is brought in, the furnace again undergoes changes which cannot be favorable to the quantity of fuel used, because all changes in a blast furnace, no matter of what nature, are accompanied either with a loss of fuel or a loss of metal. There is an advantage in storing fresh coal for 2 or 3 months, or even for 6 months, because the moisture in it becomes equalized; it also causes the coal to mix, and become more uniform in the aggregate. When stoked away more than 8 or 9 months, coal rapidly deteriorates in quality, and must be mixed with fresh to make it suitable for iron furnaces. Sometimes it is necessary to damp the fresh coal with water, at other times it is a vicious habit of the workmen. If fresh coal is used in such a condition, it works very badly in the furnace; for the wet parts, instead of burning well, diminish the fire, while the dry may become red-hot, and decompose the steam issuing from that which is damp; thus considerable fuel is wasted. It is advisable to have water near a coaling ground, in case of accidents in consequence of stormy weather; or for damping the dust, when the weather is too dry; but it is a bad practice for colliers to use it too freely in drawing coal.

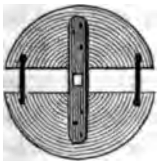
Good charcoal looks perfectly black, glistening, and has a glassy fracture. If its appearance is dull and velvety, it is either drowned, or charred at too low a heat, and is weak. Good coal shingles, like fragments of porcelain, and resists a strong pressure gradually applied, but is easily broken by a smart stroke. That which is well charred is hard, and does not soil the fingers in a fresh fracture. All fresh coal, and good old coal, floats on water; drowned coal sinks in water and burns without a flame, even if the fire is urged with a bellows. That containing more than 20 per cent. of moisture is not good for smelting iron, but, it is often superior to dry coal in bloomery fires and forges, for smelting lead, copper and other metals.

The price paid for chopping a cord of wood, varies from 30 to 40 cents; wood-choppers furnish their own axes and board. The highest prices are paid for chopping saplings, and crooked and hard wood, and the lowest prices for chopping straight tall timber, of not less than 8 inches, and not more than 20 inches in thickness, although this is in fact the most profitable for charring. The chopping of hard and knotty wood, costs more than clear and soft wood. Colliers receive from 1¾ to 2 cents per bushel of coal, of 2,600 cubic inches, delivered in the furnace yard; 40 bushels are generally claimed as the yield from hard wood, and 35 from pine and soft wood per cord. Good colliers frequently furnish from a cord of good wood 45 bushels. Charring in ovens costs from ¾ of a cent to 1 cent per bushel of coal. This includes hauling, charging the oven, charring, and the delivery of the coal at the tunnel-head. Less attention is paid to the hauling of coal from the woods than it deserves. It is generally performed on wagons, with boxes that contain from 100 to 250 bushels, according to the state of the roads and the strength of the team. When the roads are bad, much coal is often lost by being shaken to dust in these boxes. This often amounts to 12 or 15 per cent. The vibration of the boards is the cause of this loss. Good wagons ought not to waste more than 5 per cent. As it is the stiff boards that break and grind the coal, it will be more economical to line the wagon boxes with thin lath, or willow twigs. The store-houses should be divided by massive stone or brick walls, to prevent extensive loss by fire. If divisions into small compartments cannot be conveniently made, a number of small sheds, at sufficient distances from each other to escape, if one happens to get on fire, will answer. The best means of subduing a fire in the coal or wood shed, is to remove all the materials not on fire to a distance, and cover the burning mass with coal-dust, sand, or even ore if nothing else is at hand. Water is of little avail in such cases.

Peat, or Turf, and brown Coal: with these we include all that coal which does not form coke, and is younger, or of a more recent formation than bituminous coal or anthracite. This material is not much used in metallurgical operations. As good fuel can be had abundantly, at reasonable, and even low prices all over the United States, there is no inducement to use this inferior mineral. All of it, which is either found in bogs, in alluvium, or in tertiary rock, is generally very impure, brittle and damp, and with very few exceptions, perfectly useless in its raw state for any of the operations we have under consideration.

Turf-Charcoal.—We refer to this article not because it forms a cheap fuel but for its peculiar quality. When pure turf, which contains not more than 5 or 8 per cent. of ashes, is first triturated in a mill, such as is represented in fig. 174, and then strongly pressed in the form of bricks so as to remove most of the water, and afterwards air-dried, it may be converted into good strong charcoal. It is charred like wood, either in pits, heaps, or ovens; but, not necessarily in such large quantities. A pit of 10 feet in diameter, is sufficiently large to secure a successful charring; such a pit is burned in 8 to 10 days.* Brown coal may be charred likewise; it is not however formed into bricks or lumps, but simply ground with a little water, and then charred in coke ovens, like bituminous coal-slack.

FIG. 174.



Peat-charcoal has peculiar advantages for welding steel and iron, and excels all other fuel in this respect. It facilitates the welding steel to steel, or steel to iron, or working of small iron, and causes the adhesion of the metal. It is impossible to account for this peculiar effect except by the composition of its ashes, which consist chiefly of lime, clay, oxide of iron, silex, a large quantity of phosphate of lime, and a little gypsum. These substances form a very fusible slag. It is the phosphorus, which in combining with iron or steel, causes it to be fusible, and, suitable for welding. This peculiarity of the ashes of turf is injurious to pig iron, which must be cold short in all cases when smelted by turf, but it may be advantageous in smelting lead ores, particularly those refractory lead ores which are smelted for silver.

Mineral-coal, Pit-coal, or Stone-coal.—The various kinds of coal belonging to this class, constitute so extensive a mineral treasure in the United States, that a mere enumeration of the extensive coal fields of the country would occupy more space than we can spare. In the third part of this work we shall allude more particularly to the application of the various kinds. All this coal is black, and forms a dark brown or black powder; burns more or less freely, with or without flame; and is generally very pure, and free from ashes, the quantity of which varies from 1·4 to 7 or 8 per·cent. A classification of this coal into lignite, bituminous coal, and anthracite, according to mineralogists, is not proper in our case; we divide it, first,—into mineral coal, which forms charcoal, to which turf and brown coal belong; secondly,—into that class which forms coke; and thirdly into anthracite, which forms neither charcoal nor coke, and merely changes to ashes on being exposed to the strongest heat. We have just been speaking of the first class, and shall confine the following remarks to the second and third classes.

Bituminous-coal.—Under this class we range all that mineral coal which forms coke; that is, it swells up on being exposed to heat, burns with a bright flame, blazes, and, after the flame disappears, there remains a spongy, porous mass—coke,—which burns without flame like charcoal. We also range under this class of coal the Nova Scotia coal,—the Frostburg coal of Maryland,—Richmond, Virginia, coal,—some North Carolina coal,—the coal of all the western fields belonging to the Mississippi valley,—the coal in Oregon and in California. There are, indeed, coal beds in these localities which are closely allied to either anthracite or brown coal, but we confine our classification to that kind which alters its form on being exposed to heat. It is frequently divided, by miners, into various sorts, but as these are arbitrary, we do not notice them. The only points which claim our attention, are the chemical composition and the form of the coal.

In its composition we find chiefly carbon, oxygen, hydrogen, nitrogen, sulphur, and ashes, with a little water, which has been absorbed by the crevices. The following table shows the comparative composition of various sorts of mineral fuel.

Table showing the Composition of

	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ashes.
Turf	58·09	5·93	31·37	4·61
Brown coal . . .	71·71	4·85	21·67	1·77
Hard bituminous coal . .	82·92	6·49	10·86	0·13
Cannel coal . . .	83·75	5·66	8·04	2·55
Coking or backing coal .	87·95	5·24	5·41	1·40
Anthracite . . .	91·98	3·92	3·16	0·94

Quantity of Heat.—The most important point, and one which has a direct bearing upon the value of coal, is the quantity of heat, which it can evolve in combustion. If we assume that the quantity of ashes is equal in the four substances mentioned below; that is 5 per cent. in each, and suppose further, that pine charcoal furnishes 100 parts of heat,—the following table shows the quantity of heat which must be liberated in their perfect combustion.

Kind of coal.	Carbon.	Hydrogen.	Water.	Quantity of heat.
Brown coal . . .	69	3	23	78
Coking coal . .	75	4	16	87
do. . . .	78	4	13	90
Anthracite . .	85	3	7	94
Pure carbon . . .	100	–		100

Quality of Heat.—The degree of heat which may be produced by coal of the above composition, on the supposition that pure carbon produces 4420°, is, in the first 3890°; in the second 3945°; in the third 3999°; and in the fourth 4142°. These results imply of course, perfect combustion; that is,—neither too much, nor too little oxygen is present. But this is practically almost an impossibility; therefore, these degrees of heat never can be realized, although the quantity may be.

If one ton of pure carbon is considered to be worth one dollar, the same weight of anthracite is worth 94 cents, that of soft, or bituminous coal, from 85 to 90 cents, and that of brown coal only 78 cents. As the degree of heat generated from fuel is another consideration, particularly in smelting refractory metals, such as iron, it is manifest that anthracite, of all crude mineral coal, is, next to charcoal, the most valuable fuel. In treating of assays heretofore mentioned, we assumed that a large quantity of hygroscopic water was present; but our coals generally are almost entirely free from it, particularly the anthracite; indeed we may assert that the quantity of water in the best bituminous coal is not more than 5 to 12 per cent. Porous, and slaty coal, and all that which is liable to slack by exposure to the air, contains more water, in proportion to its tendency to slack.

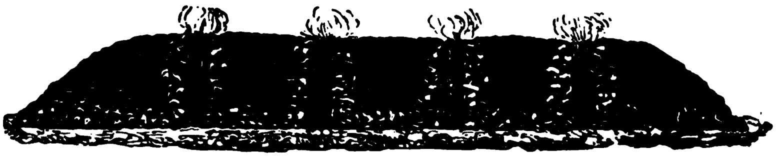
Besides, we must consider the quantity of ashes as well as the quantity of water, in the valuation of coal. The loss of heat occasioned by water does not depend merely upon the quantity; it is occasioned also by the conversion of it into steam; whereas the loss of heat from ashes is in direct proportion to their quantity, although not, perhaps, in all cases. The ashes of mineral coal consist generally of silex, clay, gypsum, iron pyrites, oxide of iron, lime, magnesia, and often chlorine and iodine. It is doubtful if the iron, lime, magnesia, and even alumina and silex, are present in their oxidized state, nor is it likely to be the case in the presence of so much hydrogen, particularly in anthracite, coke, fresh charcoal, and the more dry and compact kinds of bituminous coal. If, however, it does occur, the ashes form as well fuel as carbon and hydrogen, for in absorbing oxygen these metals liberate heat. This is certainly the case with the iron pyrites, in which not only the sulphur, but also the iron in combination with it, forms fuel and furnishes heat. In porous, slaty, and damp coal, we may suppose the ashes to be in an oxidized condition; and if they amount to more than 40 per cent., in a mineral coal, it ceases to be available as fuel. Where the metallic ores are brought in direct contact with the fuel, the quantity of ashes should never be more than 10 per cent., and in easily vitrified metals, such as lead and iron, not more than 5 per cent.

When stone coal is used in its crude state no particular preparation is necessary; it is taken from the mine directly to the furnaces. There is even no need of protecting it against rain, or water and air, for a limited amount of moisture is generally advantageous; in its action with atmospheric air, it causes the decomposition of pyrites and consequently removes sulphur. The only preparation for this coal is to break it into pieces of a uniform size. Slack coal should be slightly damp, before using it; this causes it to bake, and form coke in the furnace, which admits of a more liberal passage of air than dry coal in dust, which is very apt to cause solid cakes, impenetrable by air.

Coking of coal.—Mineral coal is converted into coke for the same reason that wood is charred, and the operation is similar in both cases. An essential condition in forming coke is that the coal, on being heated, swells and changes into irregular spongy masses, which adhere intimately together. It is generally asserted that this operation is chiefly designed to expel sulphur; but we contend that its main object is to expel hydrogen and form a coal which is not altered by heat. This species of coal is one of the requisites in most smelting operations, the absence of hydrogen is another. But little sulphur is generally expelled in the operation of coking; for, if the coal is sulphureous, the coke obtained from it is invariably so. Since both sulphur and hydrogen are injurious to most smelting operations, the collier must aim to expel as much as possible of each. It is only when there is no other substance present to which they may adhere, that they both are driven off by heat. The sulphur cannot be entirely separated from coke, or from carbon, no matter how high the heat may be; neither can all the hydrogen be removed from carbon by simply heating the compound. If oxygen is admitted to these combinations, both sulphur and hydrogen may be almost entirely expelled, that is, provided the oxygen is not introduced under too high or too low a heat. It follows, therefore, that if, as is actually the case, we need coke as pure, or free from volatile substances, as possible, the coking must not be performed in either iron retorts, or in close ovens. Where the chemical composition of coal is various, different methods of treatment are required; these are effected either in the mode of work, or in the apparatus in which it is performed.

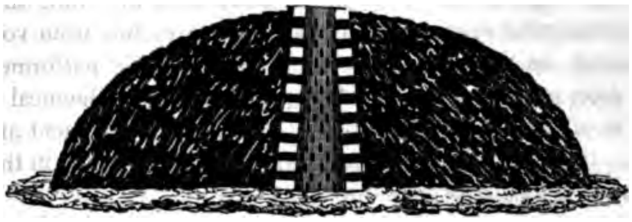
Coking in the open air.—In selecting coal for smelt works, we should choose those kinds which are the most free from ashes, sulphur, water and hydrogen; these are the purest and form the strongest coke. The strength of coke however, as well as that of charcoal, depends on the degree of heat which is used. When coal abounds in sulphur, as well as bitumen and water, the best mode of coking it is in rows or clamps; that is, in a long pit or heap, a section of which is represented in fig. 174. The length of such a heap may be from 20 to 100 feet, or, in fact, it may have any length; but its width must not exceed from 6 to 12 feet. If the coal is very impure the heaps must be narrow, but if it is hard and pure, it may be charred in wide rows. It is advisable in all cases to perform the coking near the furnaces; even in the furnace yard, the transport does not form an objectionable consideration, because the yield of coke is universally at least half the weight of the coal, and in most instances more than that. Now coke is comparatively more friable than stone coal, and its dust is worthless; the loss prevented by coking in the furnace yard therefore, is more than sufficient to pay the higher cost of transporting coal from the mine to the furnace.

FIG. 174.



In a row, such as is represented above, the coarse coal forms the skeleton of the heap inside, and at distances of 8 or 12 feet, a kind of chimney is constructed with it. If coal coarse enough for the purpose cannot be had, a flue is constructed of loose fire-brick on the floor, over the whole length; this forms an air channel. Chimneys are erected of bricks in the proper places, as shown in fig. 175. Sometimes, especially where wood is cheap, a longitudinal channel, and also cross channels are formed with it, and likewise the chimneys which are constructed of sticks. The best plan, generally, is to form air-channels through the bottom and also the flues or chimneys, of coarse well-charred coke; these do not swell; they hold good fire, and cause no loss,—for what is burned in one kind of coal is saved in the other; besides, this method furnishes the best coke. One of these long heaps of coal is from 3 to 5 feet high, according to the kind of coal; it consists of coarse coal, covered by small coal and, at last, by slack. Fire of wood or burning coke is applied to the foot of the pile, at such distances as will secure a uniform distribution of it and in the very vicinity of the flues which lead to the chimneys, as these are most suitable to conduct it into the interior. One end of a pile may be kindled, burn and even be finished while the other end is building; thus coke may be formed in a short time. The collier must aim to conduct the fire into the interior as quickly as possible, and heat from within outwards; in fact this operation must be done on the same principle as in charring wood. But, since stone coal is less valuable than wood, and as a higher heat is required to drive off impurities, and also more fresh air, and moisture to expel sulphur; the burning coal must necessarily be worked more openly, and under a more brisk heat, than wood. When the fire is well spread through the interior of the pile, and its progress is safe, the sides of the row are covered by coke-dust, but the base and top are kept free, so as to admit of a lively com-

FIG. 175.

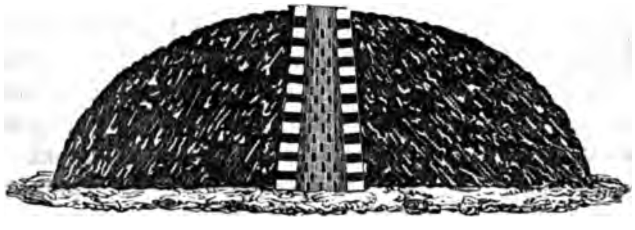


bustion and a strong heat. In fact, a large quantity of air, and if possible damp air, is required at this time to pass through the coal, if good coke is expected to be made. After the lapse of 24 hours, more or less, the heat is well distributed and the flames on the comb of the pile disappear, and hot invisible gases only escape. The pile is now closely covered with coke-dust, and left to cool; this requires another 24 hours, so that in two days' time, the coke is burned and ready to be drawn.

Coarse coal fresh from the mines is best suited for this mode of coking. It should be adopted in all cases where the coal is impure, and a good article is required; for, by no other method than this, can so good coke be obtained. Other modes will furnish more coke from the same amount of coal; but good coal is required to make coke strong and pure, such as is suitable for iron smelt furnaces. The foregoing method cannot be used when the coal is fine, that is, when it consists mostly of slack coal, because such coal is too close and does not admit of the passage of air sufficiently to form good coke. It is often charred by mixing it with small wood, chips, or bushes bound in faggots, but this is expensive, and where wood is scarce cannot be resorted to. The coal then is charred in large heaps, or pits, like wood. Such a pit may be from 20 to 25 feet in diameter, and from 3 to 8 feet high, according to the quality of the coal.

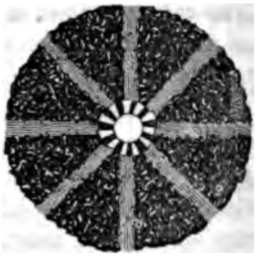
In fig. 176 a section of a heap is represented. A strong chimney of firebrick is erected in the centre, affording many flues which lead to the interior of the mass. It is built very open and without mortar. On the floor there should be a series of channels in a radial direction, as shown in fig. 177. These are formed of coarse coal, or, which is better still, of large lumps of coke, so as to be always open. Flues of firebrick do answer the purpose, but are not so favorable to the quality of coke as coke channels. These and the floor are covered with the coarsest coal which the

Fig. 176.



mine affords, and when it is exhausted fine coal is spread over them to a height of 2 feet or more, according to its quality. Fire is now applied to the flues at the circumference, and urged to a uniform and lively state. A dense smoke issues at first from the top of the chimney. This soon ceases and a white flame of carburetted hydrogen takes its place. Within two or three hours, the smoke and some fire appears at or near the top of the coal, which indicates that the fire is well spread in the interior. The remainder of fresh small coal is now gradually thrown on, but in such a manner that the heat is not checked. Some smoke ought to issue from the coal at all times, besides the flame from the chimney. Coal is therefore thrown on gradually, to the height which may be desired, so that the heat follows to the top as the mass increases. When all the coal is put on, the fire is permitted to break through, and show its white flames at the surface. Those places which are hottest, and where the white flame ceases, are covered by coke-dust; meantime other places which do not work so lively, or are behind, are urged by running an iron bar into the heap so as to make draught-holes, thus securing a more lively combustion. When all the coal is thus heated uniformly to the top, the heap is covered by coke-dust. At the foot the air is still admitted for some hours, so as to heat the heap thoroughly. When the inflammable gas ceases to appear at the chimney, the cover of dust is extended to the foot of the heap, but the chimney is still kept open for some time. Finally it is closed at the top by a slab or a cast-iron plate. The dust-cover when a white heat is perceptible below is well secured by throwing dust around it. All the vents on the surface are now covered closely, and the earth increased so as to prevent all access of air to the interior. Three days, and often four or five, are required thus to char a heap of coal. This manner of proceeding applies to slack coal. Coarse coal may be worked in rows which require less time and less attention than heaps. There is no advantage in charring coarse coal in heaps; it is coked cheaper and better in rows.

FIG. 177.



There is a different manner of working heaps than that described above, but the quality of the coke is generally inferior.

When the fire is well established in the interior, the chimney top is shut, and the heat thereby forced through the body of coal. When the fire makes its appearance at the surface of the heap, the chimney is opened again, and a lively combustion produced, which soon raises a high heat, and shortly finishes the operation. The coke obtained in this way, is generally strong but not so pure as that made by the former operation.

The heap is always well cooled before coke is drawn, which requires from one to three or four days, according to its size. When the coal abounds in sulphur, the heap is opened in places before it is cool, by means of a crowbar, and water is thrown upon the coke although still red hot. Thus a large quantity of sulphur may be expelled, which will be manifest by a strong smell of sulphuretted hydrogen. The effects of this mode of driving off sulphur on the other qualities of the coke are somewhat doubtful; for it invariably has a tendency to weaken the coke and cause it to be spongy and friable. It requires, therefore, a strong coke, which has been produced by a strong heat, to resist the weakening influence of water. We shall presently describe a better method for expelling sulphur.

The quantity of coke produced from coal varies according to the quality of the coal, and the mode of operation. It is not often that more than 50 to 55 per cent. by weight is obtained in rows; although coal which does not contain much hydrogen or water, may reach 60 and even 65 per cent. The yield in heaps is somewhat better, and can be brought, by close attention, to 60 or 70 per cent. The coke from coal generally amounts to more by measurement than the quantity of coal that is burned; this varies from 100 to 125 bushels of coke from 100 bushels of coal; it is not often less than 110 bushels.

The place where coking is performed, the coke-yard, is generally, near the furnaces and if possible on a plane which is level with, or slightly elevated above the top of the furnaces; this is particularly the case at iron smelt furnaces. The coke yard ought to be level throughout, and dug, or ploughed over, so as to remove all stones and damp places within two feet of the surface, and uniformly covered by a loose and light soil. This yard is surrounded by a ditch, into which rain and spring water flows, and which ought constantly to contain some water, which may be at hand when needed, and also moisten the ground. The object of this is to impart by these means a certain degree of dampness, but not too much, to the whole yard. In the course of the operation the yard is covered by coke dust, which, when mixed with soil, is very suitable to retain moisture; but the presence of water around the yard, enables us always to obtain damp dust by digging. A damp coke yard possesses great advantages for driving off sulphur from coal. This substance adheres tenaciously to carbon, and no degree of heat can expel it; not even with the assistance of fresh air. The best method, therefore, to desulphuret coal is found to consist in highly heated steam. Consequently, if coal is heated on a damp ground, steam is generated, which, in passing through the hot coal, is decomposed and carries off sulphur. If the heat is too high, or too low, these means are as ineffectual as any others; it is difficult to hit the exact point If moistnre is always present it will act at the proper time. When the coal is at the highest heat, no vapors will issue; the ground is dry, and none are needed.

The principles involved in making coke are exactly the same as in charring wood, with the exception that coke is less combustible than charcoal and less care and attention is required to obtain good results. The fire should always work from the interior to the exterior, and the more this is attended to, the better will be the yield. When coal is very impure, or fine, it is necessary to work with less cover, in order to make quality, but this is always accompanied by a loss. Sometimes the flues are formed by erecting poles, of 10 or 12 inches in diameter, after the coal is thrown around them, and before the fire is applied they are withdrawn. This mode of forming flues is only applicable where the coal is coarse and does not bake too much. But in such cases no flues at all are needed; the coarse coal, when piled openly, forms sufficient spaces for draught. When coal is very bituminous, and swells considerably, it must be set with large spaces, and good safe flues; and, in order to insure good work, it is coked without any cover of coke dust.

Coking in ovens.—This method is resorted to, in order to obtain more coke, work slack coal and save labor; but to the metallurgist it is of little use, and seldom serves his purposes, because coke made in ovens is never so free from sulphur as that charred in the open air. However, for the use in cupolo, in air furnaces around crucibles, for melting lead and some other metals, it serves equally as well as coke. We shall not allude to those ovens, by which the products of distillation are obtained, for they are without value here. The only valuable substance is coal tar, of which the gas works furnish as much as there is a market for.

The varieties of form in coke ovens are innumerable; we shall, therefore, confine our attention to only a few of them. In fig. 178, is represented a vertical section of a coke oven such as is mostly in use in the western states, and other regions where coke is made. It is generally built against a hill-side, and is accessible, at the top where the aperture is, by a road, so that the wagons may deposit their loads of coal most conveniently to it. The form of the interior of the oven resembles that of a common baker's oven, only it is round, as represented in the plan, fig. 179. The hearth is from 10 to 12 feet in diameter, and has a door 2 feet in width on one side. The arch is in its centre or highest point, about $3\frac{1}{2}$ or 4 feet above the bottom, and about 18 inches or 2 feet in its span. The opening in its centre is from 20 to 24 inches in diameter. The entire hearth, both the bottom and arch, is constructed of firebrick; the rough walls around these may be either of common brick, or rough or dressed stones. Two or more ovens are generally built together, as shown in fig. 180. This arrangement saves labor, because there is always more than one hand required; and two or three hands may quite as well tend as many ovens.

Fig. 178.

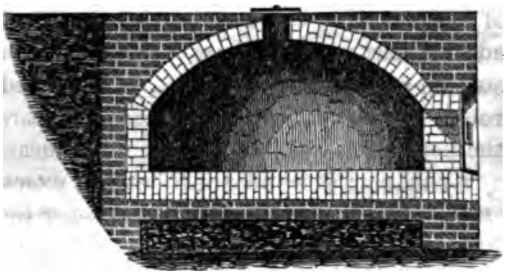
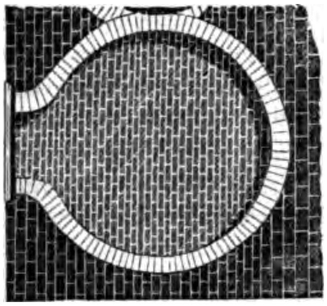


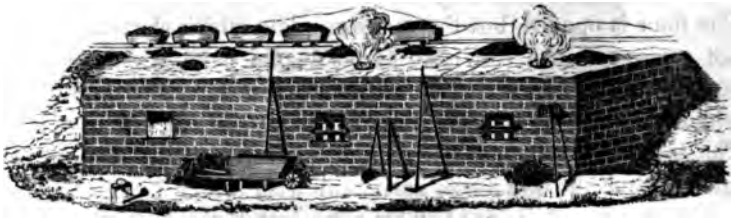
Fig. 179.



The manner of using these ovens is extremely simple. If one is cold, which is always the case when new, or on Monday mornings, a quantity of wood is first spread over the hearth, and kindled;

meantime some lump coal is added. This fire is then continued briskly, until the arch and sides are red hot. The ashes are either removed, or drawn towards the door by means of a long hook, or left where they are, in case no harm is done to the coke.

FIG. 180.



When the oven is hot, the coal is thrown in at the top, and spread uniformly, over the hearth, by another hand at the side door. The height of coal upon the bottom, depends on the kind of coke which is to be made; if it is to be close and heavy, the stratum is from 16 to 20 inches thick; and only 12 or 14 inches if it is to be pure, in which case the coke is more spongy. When all the coal, which varies from 2 to 3 tons at a time, is charged, the door is shut, either by means of a cast-iron plate, or by fire-brick. A few small apertures, however, are left open for the access of a little air, which are stopped as soon as the heat inside is strong enough to drive off the volatile matter. From the aperture in the centre of the roof, a thick dense smoke at first issues, which is soon supplanted by a bright flame. It is not good to increase the heat too rapidly by throwing in the coal too fast; there is no need of haste in charging, for nothing is gained by it; on the contrary, loss may ensue. When the coke is thoroughly heated, which takes about 15 or 16 hours, the flame ceases at the top, and all the openings in the door, and at the top are closed; still a few small crevices may be open which admit a little air. This causes the heat to become intense, and then the coke draws together, and forms a more close and compact body. This last heat, which requires about two hours, settles the coke. All crevices and joints are then carefully closed, and the oven left for some hours to cool. One heat requires from 20 to 22 hours, and when all things work well, an oven must be heated and discharged in 24 hours. This, however, depends very much on the quantity of coal which is charged. A high stratum requires a disproportionally longer time for charring than a low one; when, therefore, the object is to make much coke, and work cheap, it is not advisable to put too much coal into the oven.

The discharging or drawing of the coke ought to be done while the oven is red hot. It must be done quickly, so as not to lose too much by combustion, and also not to cool the oven, in order that fresh coal may inflame at once when it is charged. The door is opened, but the cast-iron plate which shuts the top is not removed. As the coke forms a solid cake, which is often very strong, a long heavy iron bar is driven in at the bottom, by which the cake is broken, so as to form pieces of a limited size. The coke, when thus drawn from the furnace, is dropped on the ground, and the hot mass sprinkled with water by means of a watering pot and syringe. This damping of the hot coke, cools it for removal, and in the mean time causes some of the sulphur to evaporate. When the hot coke is removed, fresh coal is immediately thrown into the oven, provided it is not too hot; for an unnecessary loss of coke is the consequence of a decomposition of the coal too rapidly.

Ovens do not furnish the cheapest coke, and of course not the best kind. Their superiority over coking in an open yard, consists in working slag coal with greater facility than it can be done in the yard. The yield in an oven, in weight and in measure, may be pushed very high, by applying a low heat in coking; 80 per cent. and even 85 per cent. in weight may be obtained, by 150 or 160 bushels, in measure. The coke thus obtained is not strong and heavy, but always spongy; it burns with flame, and is not suitable for smelting, notwithstanding however good it may be, for use in locomotives. Good coke, even if made in ovens, must be silver-gray, crystallized in columns, and shingle like good well-charred charcoal. The coke ovens near and around Pittsburg, Penn., furnish a first rate article from slack coal. An oven will not furnish much more good coke from a certain weight of coal, than the heap or row in the yard. The average return of good coke formed by a high degree of heat, is from 55 to 65 per cent. in weight, and 100 to 120 per cent. in measure.

In this country the variety in the form of ovens is not very great, and in fact there is no necessity for it; the one described above, works as well as any. Still we should like to see an improvement on that oven for the particular use of the metallurgist. A certain quantity of air, and if possible moisture, ought to pass through hot coke, as we have shown, in order to purify it. This does not take place in the ovens above described. A little air passes in at the door, but that of course cannot reach the mass of coke. Experiments have been made to introduce air by perforating the bottom; but they have been found to be of little avail, because the coke soon becomes so close as not to admit of its passage. The most successful method of producing good coke in a large quantity, and also for accelerating the work, is the construction of a channel around the inner wall of the oven, a horizontal section of which is shown in fig. 181. The air is drawn in at both sides of the door through this channel, which is about 6 inches wide, between the rough-wall and the lining of the oven, and conducted by small apertures into the oven; there may be nine or ten of such flues or tuyeres 2 or 2½ inches wide in the circumference. These air-holes must be above the stratum of coal, as shown in fig. 182. They are therefore about 2 feet from the hearth. A couple of bricks will serve to close the entrances to the main channel, when necessary. The operation of this air channel is plain. Whenever it is open, the air furnished by it will cause the gases which escape from the coal to burn, and heat

FIG. 181.

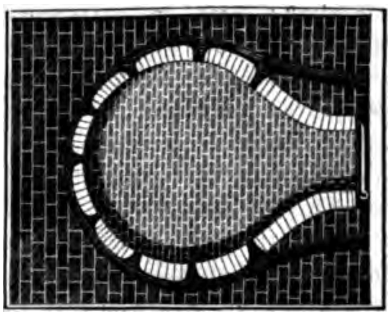
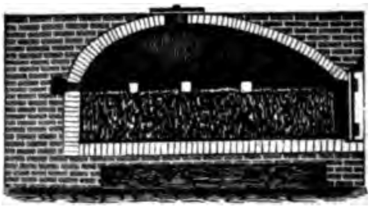


FIG. 182.



the arch and the top of the coal. By increasing the heat in the oven, it consequently accelerates the operation, and causes a stronger coke to be made. This channel must be used with discretion and judgment, for if it is either opened too soon on the fresh coal, or suffered to remain open too long on the hot coke, it causes waste.

In speculating on the best construction of a coke oven, we must remember, that a liberal supply of air, and, if possible, the presence of moisture also, is required at a certain period of the operation, in order to form good coke. In other respects, the principles laid down in charring wood are applicable here. High arches—cupolas—are generally more durable than those of less span; they conduce to a good yield and strong coke, but work slow. If, however, they are not well attended to, the yield may be worse than with flat arches, because the coal is longer in the oven. But the coke from a high arched oven is never so good as that from a low arched one. No one who bears in mind that a thin stratum of coal and low arch, with its more perfect work, furnishes better coke than a thick stratum of coal and high arch, can doubt which plan of construction is the most suitable to furnish coke for metallurgical operations. For the formation of good coke, the coal should not be higher than 12 inches, and the highest part of the oven not more than 3½ feet, from the bottom. There is little harm done in having the arch only 3 feet high in the centre, and 18 inches around the circumference.

The drawing of the hot coke is, no doubt, hard labor. An attempt has been made to facilitate it by making the hearth of the oven square, and fitting to two opposite sides, doors as large as the sides themselves, so as to remove the whole cake at once. Little if any thing is gained by this plan, for it is attended with the loss of a large quantity of coke by combustion. When the stratum of coke is not thicker than 15 or 16 inches, and a strong iron bar is driven in below, whilst it is hot, it is easily broken. The low oven, and thin stratum, offer, therefore, the greatest advantages in this country, because coal is here cheap and labor high; we can afford to waste the former, but not the latter. In addition, when we consider that the coke is more suitable, when manufactured in this way, for our purposes, there cannot be a doubt, as to the form of the ovens and the mode of work.

In respect to the preservation of coke, what has been said of charcoal is equally applicable. Coke ought to be stored under sheds for protection against rain and snow, for it absorbs water as readily as charcoal. It is asserted on experience, that coke which has been stored for three or four months, is better than that which is fresh. We may account for this in the same manner as has been done in the case of charcoal. It neither is, nor can be the moisture, which causes these advantages, for it cannot furnish heat, it absorbs it. We shall find the cause of the old coke being better than fresh, to consist in the more uniform distribution of moisture, and consequently in its more uniform quality. Coke is not so easily affected by water as charcoal, and as steam removes sulphur, there is no harm done in damping hot coke, if too much water is not used. The presence of sulphur is always recognized upon damping hot coke; but, if we wish to detect the quantity of sulphur it contains, it is rubbed together with pure oxide of iron and heated in a crucible. The grains of iron thus obtained are freed from coke by washing, and tested for sulphur by dissolving them in diluted acid; the sulphuretted hydrogen is gathered by precipitating a metallic solution.

Anthracite.—This is the most important of all the class of mineral fuel, for metallurgical operations in this country, although not in other parts of the world. Pennsylvania anthracite is not only abundantly distributed in the eastern part of that state, but its great purity, and solid form, adapt it particularly to the use of the smelter and operator in metals. The chemical composition of anthracite is similar to charcoal, from which it differs chiefly in its form, being very hard and compact, and in the greater quantity of ashes which it contains. It is, like charcoal, unaltered in form after exposure to the strongest heat; even after passing through a blast furnace, it has equally as sharp edges, and is in form exactly as it was before. The following table presents the composition of some of the anthracite of Pennsylvania.

	Composition.			
Locality.	Carbon.	Volatile matter.	Ashes.	Specific gravity.
Lehigh coal, Summit mines,	88·50	7·50	4·00	—
Schuylkill coal, Tamaqua mines,	92·07	5·03	2·90	1·57
Pottsville,	94·10	1·40	4·50	1·50
Pinegrove,	79·57	7·15	3·28	1·54
Wilkesbarre, Luzerne Co.	88·90	7·68	3·49	1·40
Carbondale, " "	90·23	7·07	2·70	1·40

The ultimate analysis of anthracite shows it to be composed of 90·45 carbon, 2·43 hydrogen, 2·45 oxygen, some nitrogen, and 4·67 ashes. Another specimen of Pennsylvania anthracite was composed of 94·1 carbon, 2·39 hydrogen, ·87 nitrogen, 1·33 oxygen, and 1·3 ashes. The ashes generally consist, like those of bituminous coal, of silex, alumina, oxide of iron, and chlorides, which generally evaporate and condense on cold objects in the form of white films. Some of this coal contains considerable quantities of sulphur, which is chiefly found in the fine parts and slack, in consequence of the coal having been broken into lumps of uniform size before use, and because the sulphureous parts are the most brittle and slaty. When we desire a relatively pure coal for our operations, anthracite should be used in large lumps.

Anthracite is the most important, and best fuel for the smelting of metals, partly because it is nearly as pure as charcoal, and generally cheaper than either that or coke. When a ton of bituminous coal can be bought at 50 cents, which is an average price in the coal regions of the West, a ton of coke will cost not less than $2, at which price many of the iron furnaces buy anthracite. The points in which the advantages of anthracite are greatest are these,—if coal, coke and anthracite must be transported, the latter is far before the first in cheapness. A ton of charcoal cannot be furnished under the most advantageous circumstances for less than $6. When we now consider that anthracite occasions no expense in the erection of char ovens, and yards, or for the superintendence of the charring operation, no interest on capital invested in a stack of wood, charcoal or coke, there is little doubt as to the superior cheapness of anthracite over charcoal and coke in melting. We shall speak of this subject more at length in the proper place, in the third part of this work.

Anthracite is not so imflammable as either dry wood or bituminous coal, but it may be made to burn quite as vividly as either, by exposing it to a strong draught, or in a large mass, to the action of air. Since there is little or no hydrogen in this coal, it burns without flame, and its use for many purposes, such as heating reverberatories, has been in so far delayed. As has been explained in previous pages, this absence of flame arises chiefly from the lack of solid, heated particles in the gases, and as transparent hot gas does not radiate heat, no matter what may be its temperature, it has been found that the anthracite flame does not heat the hearth of a reverberatory so well and so quick, as bituminous coal or flaming wood. This evil can be remedied by applying a blast under the grate of a furnace. Thus fine particles of coal are carried over by the hot gases, and the flame so formed radiates heat as well as that of any other fuel. It is manifest, that the pressure of blast, or the force of the current of air, which is to tear loose these particles of coal, must be in proportion to the refractory nature of the coal. If the draft is too strong these particles will be too large, and therefore be deposited on the hearth where the current has not sufficient strength to keep them suspended; their effect is thus lost. If the particles are extremely small and the furnaces so constructed as to retain a lively current, their subsidence is prevented. A low roof is therefore required in burning anthracite coal in a reverberatory furnace. Another consideration which has a strong influence on the formation of flame, is the size of the grate. Small grates generally furnish more flame than large ones, but only when flaming fuel is used, where the carburetted hydrogen affords the carbon as minutely as it is required. A large grate is, in this instance, more suitable to form a good substantial flame than a small one, for a gentle draught in it will produce only small particles, while a strong blast tears off large ones which are of little use. The truth of this explanation of the formation of flame, is forcibly illustrated in the reheating and puddling furnaces of the iron works. For reheating or welding iron anthracite is decidedly preferrable to bituminous coal, because it is more economical and works faster. The low roof, in the reheating furnaces, is the only cause of good work with anthracite. The same coal, with the same blast and size of grate, will produce a perfectly white flame in a reheating furnace, while we cannot obtain a similar flame from it in a puddling furnace.

Sometimes, the ashes which are formed by anthracite and deposited in the flues, or on the hearth, are a cause of objection. This evil, if it cannot be entirely obviated, can at least be greatly modified by increasing the surface of the grate. It is in connection with the deposit of these ashes that the strong draught, as we remarked before, tears loose large particles of carbon which cannot be supported by the slow moving gases, nor consumed because their mass is too large and refractory.

Gaseous Fuel.—In smelting and other operations of metallurgy, we do not use any natural gaseous fuel. That which is generated from solid fuel can be used advantageously only in some particular cases, of which we shall speak at the proper time. If we generate combustible gases from solid fuel and use them, we shall only accomplish, by a complicated process, those results which we can generally attain more advantageously by using the fuel itself. It would lead us farther than our space admits, to show the folly of generating gases for combustion from solid fuel, but we will show the principle of the operation, and each one may draw his own conclusions.

If we would produce the highest heat from fuel, it is necessary to convert all the carbon into carbonic acid; this can be done in any well-constructed furnace with brick walls, and in which the layer of coal on the grate bars is not too high. Seven inches for bituminous coal, and eighteen inches for anthracite, is nearly the proper height. In combustion thus conducted, we obtain the highest heat, and the largest quantity of it. The principle involved in forming gas, is to use a thick layer of coal, and convert all the oxygen and carbon into carbonic oxide; introducing fresh oxygen, or atmospheric air, at a proper place behind the grate, and converting the carbonic oxide into carbonic acid. If the simple combustion of solid fuel in the grate is perfect, we obtain just as much heat as in forming gas; indeed, there cannot be the slightest difference; for perfect combustion will furnish the same amount of heat in both cases. It is asserted that perfect combustion is more easily accomplished in burning gas than solid fuel; we contend that this is not the fact, and experience confirms our statement. In well-constructed furnaces there is less fuel used, by burning it directly, than in forming gas. The use of gas in reverberatory furnaces is inconsistent with sound principles. We have seen that flame is required in reverberatories; but by forming and burning carbonic oxide no flame is produced, and no radiation of heat can be expected.

One of the objects in the construction of furnaces, is to condense the heat into the smallest space possible, in order to diminish the surface of apparatus, and, consequently, the radiating surface. In generating gas from solid fuel this object is neglected, and the consequence is a loss of heat, both by conversion and radiation. All combustion, as well as the use of the heat which is generated, must be confined to the smallest possible space; any unnecessary extension of space causes loss in the degree and quantity of heat. In fact, the generation of gas from fuel, for the purpose of subsequent combustion, appears to us like pumping water by hand upon a water-wheel, in order to drive a mill thereby.

The only useful application of gaseous fuel is when hot gases are prevented from passing away into the air, and their heat, instead of being wasted, is abstracted for some valuable purpose. The investigation of this subject does not belong to this place, and it has, in fact, no connection with that of generating of heat. We shall allude to it when treating of those subjects where it is applied. In concluding this chapter, we insert a table showing the results, as calculated for various kinds of fuel.

Kind of fuel.	Degree of heat which may be generated.	Quantity of heat according to volume.
Air-dried wood 20 per cent. moisture,	2838°	25
Wood of 10 per cent. moisture,	3018°	—
Kiln-dried wood,	3163°	—
Air-dried turf 30 per cent. water, 10 ashes,	2703°	35
Kiln dried,	3378°	53
Brown coal, 20 per cent. water,	3558°	60
Bituminous coal,	3963°	85
Anthracite,	4233°	94
Charcoal, 12 per cent. water,	4413°	97
Turf-coal,	4233°	33
Coke, fresh,	4323°	92
Tunnel-head gas charcoal,	2163°	·08
" " coke,	2700°	·10
Anthracite,	2500°	—
Stone coal, bituminous,	3323°	—
Gases generated from solid fuel, and burned in separate chambers,	2200°	—

CHAPTER VI.

Means which facilitate Combustion.—In order to obtain the highest degree and the largest quantity of heat from fuel, certain artificial means are used, consisting of properly-constructed furnaces, chimneys, and blast machines. We must always endeavor to make the combustion perfect; that is, to convert all the carbon, by oxidation, into carbonic acid, and all the hydrogen into water. In fact, all substances which are susceptible of it should be oxidized to the highest degree. When one part of pure coal, by being converted into carbonic acid, liberates 8000°, or parts, of heat, it will produce only 2480° if oxidiced only to carbonic oxide. A liberal supply of air is, therefore, necessary to all combustion; for the losses accruing from a deficiency are far greater than those caused by an excess of air. In order to condense combustion into a small space, the hot gases are either drawn away by a chimney, or fresh air is forced into the coal by blast machines; or both means are resorted to at once.

Construction of Furnaces.—The forms of furnaces are modified to answer the specific objects of their construction. We shall, here, only allude to some general principles, in relation to them, which it is useful to know. The highest degree of heat which is possible, is required to form carbonic acid. That is to say, it is more safe to form it at high, than at low, temperatures. The highest heat which may be produced in forming carbonic acid, is about 4000°, while in forming carbonic oxide it is not much more than 2000°. The most important objects to be considered in attempting perfect combustion, are the thickness of the stratum of coal, and the absence of spaces in it. It must be uniformly close, and as low as possible; nor can it be too thin so long as sufficient heat is generated. Holes, or spaces in the coal through which atmospheric air may pass, are chiefly to be avoided, for such air in its passage only absorbs without producing any heat. Again, the grate surface should not be too large; for when it is, and more heat is produced than can be consumed, the carbonic acid is transformed into carbonic oxide. The smallest space, therefore, is the most profitable; or, in other words, the grate should never have a larger surface than is actually necessary. The material of which a furnace is constructed has an important influence upon the combustion. Good conducters, such as metals, lower the degree of heat, and the formation of carbonic acid becomes extremely doubtful. All those substances which surround the fire should be either natural or artificial stones; the porosity of the latter renders them preferable under the form of fire-brick, which resist the degree of heat generated in the grate; they are most suitable for this purpose. It is not in respect to its non-conducting capacity, alone, that a fire-proof material is to be selected, but its color has an influence on combustion. White surfaces form carbonic acid with greater facility than darkened, or black, bricks or stones. The spaces between the grate bars should not be too narrow, for a sufficient width facilitates the formation of carbonic oxide; this is true also of tuyeres. Coarse fuel has not such a tendency to form carbonic oxide as fine fuel; the stratum of the former may be thicker than that of the latter. Some fuel, particularly anthracite, is liable to flying, on being suddenly placed in a hot fire; this may be prevented by heating the coal gently, for some time, before charging it. When fuel is gently heated, before it is placed in a furnace, provided it can be conveniently done by waste heat, it is always attended with a good effect. The water is thus evaporated and the fuel, whether wood or coal, is prevented from forming dust. In some instances, advantages may be derived from heating the air before it enters the furnace. When this can be done by waste heat, these advantages may be measured by the ratio of heat indicated, or rather the difference between the feeding air and the heat in the furnace. If 4000° are generated in the furnace, and the feeding air is introduced at 500°, $\frac{1}{8}$ of the amount of fuel may be saved by this hot air. But, since hot air facilitates combustion, and consequently the formation of carbonic oxide, all the advantages gained by it may be lost in its combustion. In smelting operations, hot blast has peculiar advantages, which it would be out of place to notice here. There are other means for increasing either the quantity or quality of heat, such as the grinding and washing of fuel with warm water to remove gypsum and other soluble salts; also pressing, drying, and charring it: all these have been alluded to in former pages.

Chimneys.—The most common means to produce draught, are chimneys. It is not our object to present a theoretical investigation of this subject, which, in fact, would be useless here, in our case; but to point out some leading principles which should be observed in the construction of chimneys. In all cases, the walls of a chimney can never be too thick, particularly the rough wall. Heat is the power which produces the motion of air, and it ought to be preserved. The height of a chimney is not important; its top must of necessity be raised over the roof of the buildings, and that height is, in all cases, sufficient to ensure perfect combustion. In any case there is no need of a higher chimney than will answer to carry off the gases beyond the reach of harm. When combustion is perfect, carbonic acid is formed, which is far heavier than atmospheric air, and, therefore, requires a high degree of heat to ascend a tall chimney. The lowest stack is the most profitable in this case, for it loses less heat by radiation than a high one. In all metallurgical operations, there is sufficient waste heat for producing draught, and hardly a case occurs in which a want of heat, when it is properly applied, is the cause of a want of draught. It is, therefore, of no advantage to have high chimneys; but it is essential to have them wide enough to abstract and remove the hot gases produced in the grate. The gases generated from different kinds of fuel are not equal in composition; thus, wood and bituminous coal generate a large quantity of water, or steam, besides carbonic acid, while anthracite and charcoal do not. These latter generate chiefly carbonic acid of a specific gravity of 1·52; and if we take the nitrogen which passes through the grate into account, the burnt air is still heavier than atmospheric air, in proportion of 109 to 100. It is evident that a certain quantity of heat is required to render this of the same specific gravity as the atmosphere, and an additional quantity to set the gases in motion; when we consider, also, that large surfaces radiate much heat, the conclusion is irresistible that low stacks are more profitable in the consumption of fuel than high ones. Steam is not half as heavy as atmospheric air; and where it is mingled with the products of combustion, there is, therefore, a stronger motion. Hence, we conclude, that a chimney for a wood fire may be narrower than one for bituminous coal; while for bituminous coal it may be of smaller dimensions than one for anthracite and charcoal.

We may state, in general, that vertical chimneys are preferable to inclined. That as little heat may be lost in the ascent of gases as possible, the interior of a chimney ought to be as even and smooth as it can possibly be made. The bricks of the lining must be so far refractory as not to be vitrified or melted by the heat which passes. The advantage of the round form for a chimney is small, and when the difficulties of construction are considered, square stacks are preferable. It is a practical question to determine the size of grates, flues, and chimneys. We shall allude to particular cases, because this is a subject which on account of the great varieties of fuel, the form of furnaces, and local distinctions, cannot be decided by general formulas; these, at least, are so complicated that confidence is not placed in them.

As an illustration;—the spaces between the grate bars are generally such, that $\frac{1}{4}$ of the whole surface of the grate admits of the passage of air; but this is contracted to $\frac{1}{16}$ and less for burning wood, and enlarged to $\frac{1}{2}$ for anthracite. The spaces are narrower for a strong, than for a weak draught, and wider in a puddling than in a reheating furnace. In those furnaces in which roasting is performed, the spaces are considerably wider than in common furnaces, but in those which serve for smelting they are the smallest. There are, in fact, so many circumstances having an influence upon this subject, that it will trespass too much upon our limits to speak of them all here.

Blast Machines.—In most metallurgical operations, the fire is urged to the proper degree of heat by forcing air into the fuel. This is done by machines which are driven by some power. The pressure of the blast thus generated, and the velocity with which it enters the fuel, is greater or less according to the kind of fuel, and the effect which it is intended to produce. The most common blast machines are smith's bellows: these, however, are of limited use in smelting metals. They are confined to the heating and melting of small quantities, with which we have no concern. Some bellows of this form have been constructed entirely of wood, which produced a stronger blast than the leather bellows, but they have become antiquated, and are not any longer employed. A great deal of ingenuity has been expended in the construction of blast machines, but these we shall not refer to, as they possess merely an historical interest. We shall describe only those which are at present in actual operation, barely mentioning such others as may be of use.

The Fan.—This machine is represented in figs. 183 and 184. It is on the most improved plan, and affords more pressure than those of any other form. It has been described on page 104, and we shall add here only such remarks as apply to the principles involved in its construction. Whatever may be the form of a fan, the casing ought to be strong and heavy, in order to resist vibrations, in case they are produced by the vanes; the stationary part of the fan is, therefore, of cast-iron. The movable parts must be as light as possible. A strength sufficient to withstand the destructive effects of motion, is all that is needed, for the resistance of the air is so small as to demand no particular attention. The axle of the vanes ought to be of fine shear steel, the ends of which are hardened, and run in bronze or anti-friction metal.

The pulley should not be too small; at least not less than four inches for small fans, and six inches for large ones. The cross, which is fastened to the axle, and which bears the four vanes,

FIG. 183.

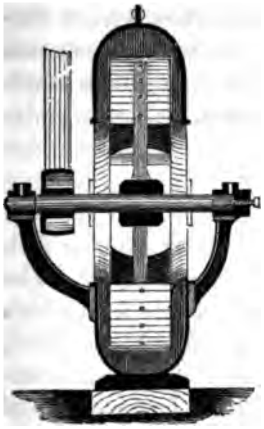
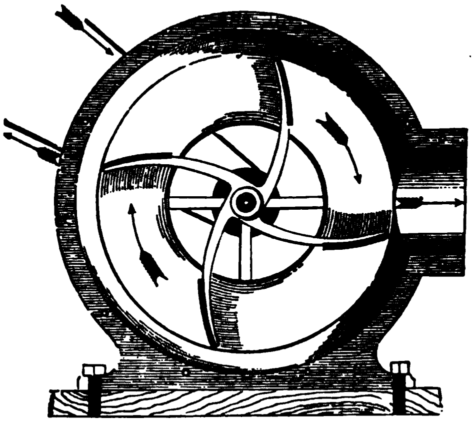
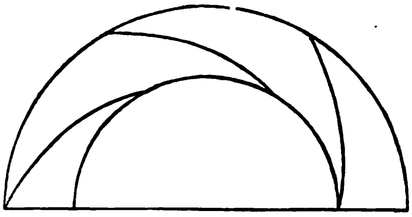


FIG. 184.



must be of good wrought iron, and as light as possible. It is not sufficient that the arms of the cross are of equal length, and that it balances well when turned round with its axle; the centre of gravity in each of the arms, should be equidistant from the axis of rotation. This implies, that the arms must be exactly of similar dimensions, and of uniform metal. As the vanes are made of sheet copper which is thin, they can easily be made of exactly the same weight, and have their centres of gravity placed in a circle described by the rotation of the axle and arms. The number of vanes has little influence on the effect of the machine, more than four are useless. The casing of sheet-copper, which is riveted and soldered to the vanes, may be merely thick enough to retain its form; for there is no pressure upon it which cannot be resisted by a thin sheet, bent as it is into a concave form. The moving parts of the machine should be worked with the greatest attention, so as to be smooth, and run true, or without waving. The effect of these machines is not dependent on the size of the vanes. It has been ascertained, that the best size for a vane is 1·5, or, in some cases, 1·4 or 1·6, of the size of the nozzle; or the sum of all the nozzles which are supplied by the fan. If there is more difference between the nozzle and vane, the effect will be diminished. The distance between the vanes, in the circle, is of great importance. If the space from one to another is larger between any two vanes, than between others, the apparatus will vibrate, and lose power. The size of the suck-holes, around the axle, is variable; no harm is done if they are as large as possible. The centre in the iron casing must be well turned, or bored out, and the copper collar at the inner casing must be turned true, so that only a small space is formed at the centres between the inner and outer case. In fig. 185 a blower is represented, in which a hermetic packing is very ingeniously accomplished.

FIG. 185.



Fan-blowers furnish the most uniform and the best kind of blast, and they should be used more extensively. The only objection to these very useful machines is a want of pressure, and, as most smelting operations depend more or less on pressure, this objection is well founded. In a common old-fashioned fan, scarcely more than ⅛ of a pound of pressure can be produced by the greatest velocity; but with this improved fan ¼ of a pound may be obtained by a limited speed. The diameter of the axle and vanes have some influence in producing pressure. It has been ascertained that a diameter beyond three feet, for the movable part, is of no great advantage; the weight of the machine, in such a case, increases too rapidly with the diameter, without affording an equivalent in effect. Fans have been driven to make 1800 revolutions per minute; but from 600 to 1200 revolutions may be regarded as a practicable speed. The effect of a fan should be as the cube of the velocity, but that is never obtained, and in very few instances it approaches near the square of the speed. The main loss of effect takes place at the centres, with the old fans; as they did not admit such close fitting joints as the one represented in the cut, no pressure could be obtained at the greatest velocity. The fan, fig. 184, is perfectly secured against these losses, and as it causes little or no friction, it is best to produce pressure. It has been proposed, and experiments have been made, to cause a higher pressure in fan blast, by blowing with one fan into another, and thus multiply the pressure by multiplying the fans. We are not aware with what success these experiments have been made, but should think that, if conducted with judgment, they would result favorably. The direct cause of pressure in the air, which is whirled round, is centrifugal force, the laws of which are very well known. It is not, therefore, difficult to estimate the effect of these machines. There may be elements in the construction of the fan, which are not sufficiently developed to be perfect; but when this subject is referred to the theory of turbines, some definite rules ought to be found. It has been stated that an angle of 43° is the best for the vanes, others assert that a radial form is the best, and again, others draw a spiral over the whole space from one vane to the other. Little difference seems to have been found between these forms, from which we are inclined to conclude that no one of them may be the right one. It is probable that the form of vanes is as intricate a subject as that of the bucket in a reaction water-wheel. However simple this machine appears to be, very little is nevertheless known of the principles on which it acts, and of course nothing of the elements of its construction.

Cylinder or Piston Blast Machines.—Where pressure is required, these are the most useful machines. When they are well built, any amount of pressure may be produced. Cylinder machines are constructed with a double and simple stroke; the wooden ones are generally of the latter, and the iron of the first description. In addition, there are machines with one, two, and three cylinders. One of the chief aims in constructing a blast machine must be to produce a uniform pressure. This is difficult, even with a regulator attached. This subject should receive the most scrupulous attention, as we shall presently show. There is still room for improvements, as most of our blast machines do not furnish that uniformity which is required. Fig. 186 is a vertical section of a wooden blast machine most usually made. A, A, are two simple working cylinders, in each of the pistons of which there are two valves. On the top of these cylinders, there are valves which lead to the regulator B, in which a piston moves that is connected by an iron piston-rod with the weight C. A balance beam D, sets both pistons A A in motion, and is itself moved by a crank-pin and connecting-rod from the wheel E, which, again, is moved by a water-wheel or a steam-engine. The whole machine is fastened to substantial timbers, which rests upon a good foundation of hewn stones. These cylinders, and the regulator, are from 3½ to 5 feet in diameter, and not often of more than 3 feet stroke. The construction of the cylinders is a delicate operation. It is best to compose the whole of segments of circles as shown in fig. 187, which are cut out of 1½ inch plank of dry ash wood, and well glued together. The fibre of the wood runs then parallel with the circumference. This form secures great solidity, prevents warping, and affords so much strength, when the thickness of the sides is at least three inches, that no iron hoops, or binders of any kind are required. As the movement of the beam does not produce a perfectly parallel motion in the piston and its rod, it is necessary that the stroke should be short. When the interior of the cylinders is perfectly round and smooth, there is not much friction produced, provided the surfaces are well covered by a coating of fine plumbago. Fat, grease, or oil of any kind should not be put within a blast cylinder. Black-lead and glue, formed

Fig. 186.

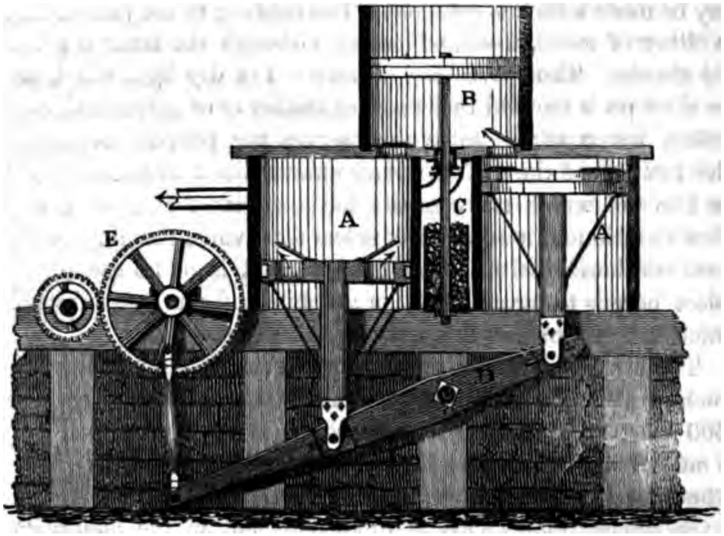
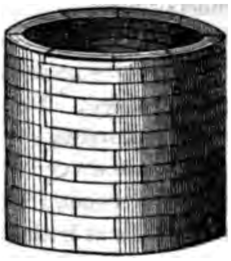


Fig. 187.

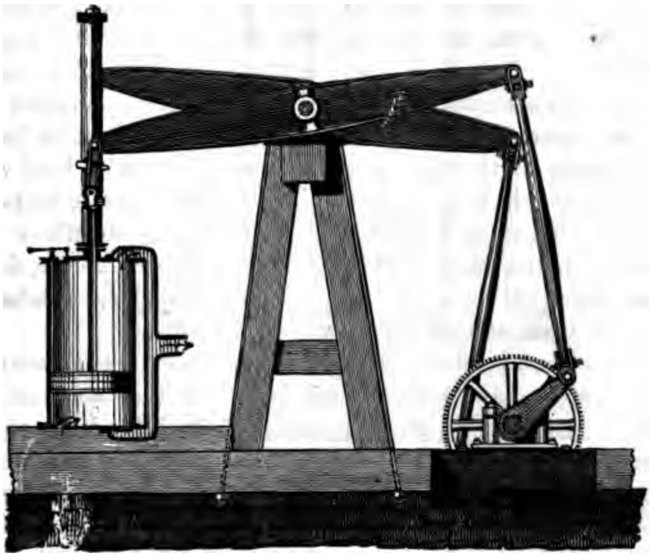


to a thin paste, is the best lubrication in this case. The weight which holds the piston in the regulator is somewhat bulky, even when of iron, because the surface of the piston is large; its weight added to the balance weight, must be sufficient to counterbalance the pressure of the blast. From 15 to 16 strokes per minute, may be made with this machine. The packing of the pistons may be either of metal, wood, or leather, although the latter is generally chosen. The valves are constructed of dry light wood, and the close pit is secured by a piece of leather or of galvanized india rubber, which at the same time serves the purpose of hinges. The interior of the cylinder is sometimes lined with hard wood, the fibres of which run opposite to the others, that is, vertically. Thus the friction, it is asserted, is less than when the fibres of the wood run horizontally. This improvement is of no use, for the object here is to form a lining of graphite and glue,—a substance which is hard, and causes very little friction.

These blast machines are rather expensive, costing nearly as much as iron ones; a good machine of this kind will cost from $500 to $600, whilst an iron machine, which furnishes equally as much blast, can be bought for $700 or $800. In these wooden cylinders the pressure cannot well be increased above ¾ of a pound to the square inch. This is quite sufficient in the majority of smelting operations, but if we consider the durability of iron, the less degree of friction attending it, and, if required, the greater pressure that can be obtained, there cannot be any hesitation in deciding which is the better material for these machines. No excuse can be given for the erection of wooden blast machines, except the scarcity of iron in consequence of the difficulties of transportation.

In the annexed cut, fig. 188, a section of an iron beam blast machine,—as these are frequently found in the Western States—is represented. Here are two cast-iron cylinders, with double and four feet strokes. The balance beams, which are either of wood or iron, are driven by cranks and wooden connecting rods. The stationary beam, which supports the balance beams, is set in strong stone walls at both ends, and may be supported in the middle by an iron or wooden frame. The cylinders are generally from 30 inches to 3 feet in diameter. Such a machine furnishes readily from 1000 to 1200 cubic feet of air per minute. The whole of it must be firmly supported by a strong stone foundation. As it does not furnish blasts of equal pressure free from oscillations, it is not suitable to be used at blast furnaces for smelting. A regulator must be appended, in such a manner as to be applicable to those cases where a uniform pressure is required. It may serve

FIG. 188.



in the form represented for feeding forge, refining, and other fires; but even in these cases a uniform density of blast is advantageous.

The erection of regulators is in some cases inadmissible, in others it is expensive and inconvenient. This has led to the construction of the following machine, in which an attempt is made to produce a steady blast without a regulator. The object is not quite accomplished; still the machine is far better than that with two cylinders, represented above, and may generally be used without a regulator. In fig. 189, a machine with three cylinders is shown; it is partly a sectional view. It needs no further explanation; it is constructed of iron, and the piston-rods work from below, moving in guides to secure a straight and parallel motion. This machine has the great advantage of being compact, strong and cheap. As the arrangement by which the air is conducted from the cylinders cannot well be shown in the above drawing, we present fig. 190, which represents a vertical section in the opposite direction. Two hollow cast-iron beams, A, A, support the cylinders, and one serves in the mean time as the conductor of the blast, in the other the sucking-valves are located. At the top is a round pipe, B, running the length of the machine in which the blast is gathered from the upper parts of the cylinders. The upper and the lower pipes are connected by an upright pipe, and from this the blast is conducted to the desired spot at the furnaces. We observe in this machine that all the valves are situated so as to be nearly vertical when shut; this is partly to save power, because the lifting of a horizontal valve causes an unnecessary expansion of air; and partly, to avoid the noise made by the clapping of so many valves, which is greater when they are horizontal than when vertical. The valves are made of wood, although the machine is of iron. The other arrangements of the machine, in which there is nothing of particular importance, we shall allude to hereafter.

Fig. 189.

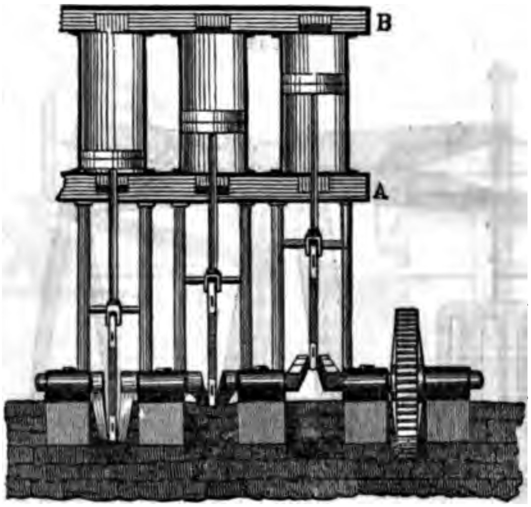


Fig. 190.

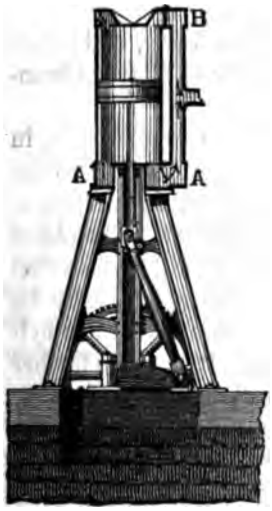
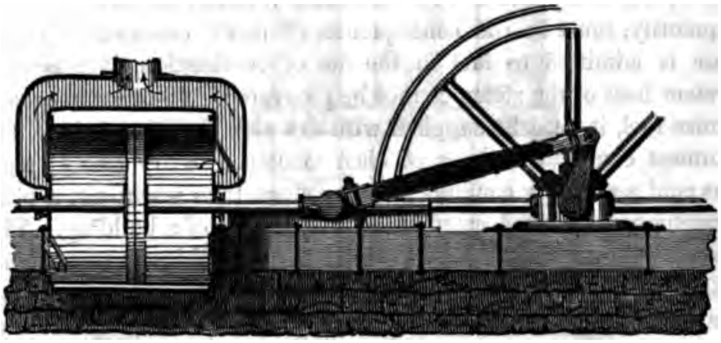


Figure 191 shows an iron bellows with horizontal cylinder;

it is the most common blast machine at large furnaces in this country. The cylinder is frequently found to be from 5 to 8 feet in diameter, and generally with as much stroke; the latter, however, is often increased to 1½ of that of the diameter. These machines are always double acting. The piston-rod is frequently found to pass through both heads, so as to balance some of the weight of the heavy piston, thus the friction is somewhat diminished. One end of the piston rod is attached to a connecting rod, which is joined to the crank of a water-wheel or a steam engine, or it is driven by a gearing of cog-wheels. The first plan is the best. These horizontal blast cylinders afford some advantages over the vertical cylinder. A foundation is more readily made and secured for them, than for a vertical cylinder, and the waste room at each head can be diminished to a minimum, in consequence of the position of the valves. The principal disadvantages in this machine, consist in a far greater loss of power from friction than in vertical cylinders. In the case represented, there is another disadvantage, arising from the position of the air-pipe which leads from the blast-valves; that pipe should be below the cylinder instead of above, thereby affording a more advantageous play of the valves.

FIG. 191.



We forbear to notice all other forms of blast machines, because most, or all of them, are so constructed as to bring the air in contact with water. The cases in which water does no harm in metallurgical operations are very few; such as roasting ore, or refining metals; but even in these instances it is better to throw water itself into the furnace, than to drive vapors through the fuel. In whatever form water appears, it can never aid combustion, and all assertions to the contrary, are erroneous. When water is brought in contact with air in motion, it passes along with it in fine particles; but it is still condensed, liquid water, and not steam; and when this water is transformed into steam, in a furnace, it is easily understood that a loss of heat, both in degree and quantity, must be the consequence, as in all cases where damp air is admitted to fuel in the act of combustion, because the latent heat of the steam cannot be recovered. In order to economize fuel, it must be supplied with dry air; therefore it is of the utmost consequence to erect blast machines in dry places; and, as cold air always contains less moisture than warm air, a blast machine should be located in the coldest part of a building. The vicinity of a water-wheel, steam-boiler, or a leaking steam engine, diminishes the effects of a blast machine, because the air around is always supersaturated with moisture. When such engines cannot be removed from the vicinity, the blast machine should be separated from them by solid walls, and the air for feeding it drawn from some quarter whence it can be obtained in a dry state.

Parts of Blast Machines.—A blast machine should be carefully constructed, in order to obtain the best results from it. In boring the cylinder, or cylinders, the same attention is required as for those of a steam engine; and, because a wooden cylinder cannot be made exactly true, or will not continue so after it has been made, iron ones are in all cases preferable. Iron cylinders should be cast of gray, but strong iron; the thickness of large ones is generally from one inch to one inch and a half. The flanges are to be turned, as well as that part of the heads which is to fit to the cylinder, so that no packing or cement is required. The piston is generally made similar to that of a steam engine, which is without doubt the best form. A piston is represented in fig. 192, and also a section of one; its parts are screwed firmly and permanently together, and well turned; two steel, brass, cast-iron, or antifriction metal rings, are laid around it, and between these and the cast-iron body of the piston, hemp packing is driven so as to press them closely to the blast cylinder. There is generally no time for renewing the packing of blast machines oftener than once or twice in a year; but the screws A, A, A, are inserted at one side of the piston-head, which drive a wrought-iron ring upon the hemp packing, and by these means tighten the metal rings whenever it is necessary. The form and position of the valves is one of the most important points con nected with a blast machine. The dead space at both ends should be as small as possible, for air being elastic, it expands when the pressure upon it is released. The compressed air ought to be driven out altogether at each stroke, therefore the piston must go close to the cylinder heads without touching. All dead space ought to be avoided in the valve-boxes, and as this is more perfectly accomplished in a horizontal than in a vertical cylinder, the former has, in this respect, a decided advantage over the latter. We may locate the valves horizontally in the cylinder heads, even when the cylinders are vertical, as has been shown in fig. 189, but the weight of the valve is an objection to this; it acts with the same effect as waste room. The vertical valve has a decided advantage. In whatever form the valve may be applied, waste room ought to be avoided. This is a serious objection to the arrangement in fig. 189, for these valves cause much dead space. Valves should be as light as possible; heavy ones cause the air to expand, and they are apt to require frequent repairs. The wooden valve lined with leather or galvanized india rubber, is for these reasons preferable to one of metal. In order to diminish the bad effects arising from the weight of valves, their number may be increased; this affords more space passage of air without increase of weight. The other parts of the machinery are too well known by our mechanics, to require particular attention from us.

Fig. 192.

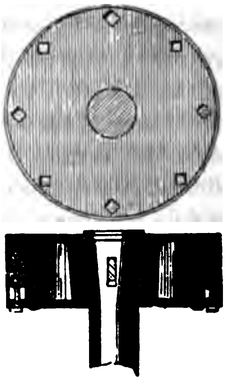
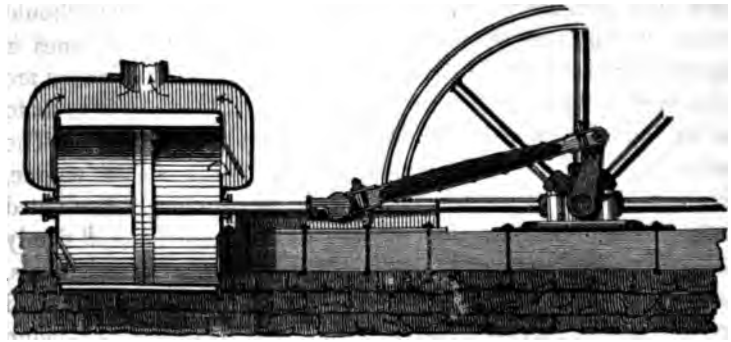


Fig. 193.



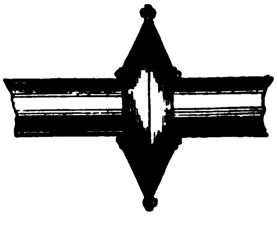
The size of a blowing cylinder depends upon the volume of air which is wanted. The stroke of the piston is generally limited by parts of the machinery depending on the locality and on the moving power; the speed, or number of strokes, is also subject to considerations of economy and locality. As the velocity of the piston is diminished, the power lost by friction is reduced, and the durability of the machine is increased. A speed of 3 feet per second is considered an average velocity. In some cases the piston is driven 4 and even 5 feet per second; but these velocities are too great for a blast machine. If we multiply the velocity by the surface of the piston in feet, we obtain the quantity of air of the blast per second; but as blast is lost by leakage and waste room, we must multiply that result by ¾ for iron cylinders, and by ⅔ for wooden ones; in the latter it was frequently found to be but half of that found by calculation. The quantity of air necessary in the consumption of a certain quantity of fuel, must be in proportion to the fuel, and so calculated as to be sufficient to oxidize it to the highest degree; to this quantity thus obtained an addition of one-fourth is made, or in other cases the quantity must be doubled. One pound of carbon requires 2⅔ pounds of oxygen to form carbonic acid, and as atmospheric air consists of 23·1 parts of oxigen and 76·9 parts of nitrogen and other substances, it follows that 100 pounds of air will convert 8·1 pounds of carbon into carbonic acid, in case all the oxygen is consumed. But this is not often accomplished; therefore 6 pounds may be assumed in reverberatories, which, in many instances, such as in reheating and roasting furnaces, is reduced to 5 and even 4 pounds of coal to 100 pounds of air. In blast furnaces the carbon is generally oxidized only to form carbonic oxide, and from 10 to 12 pounds of it, and even more, are consumed by 100 pounds of air. Now, when we consider that 100 cubic feet of air weigh about 8 pounds, or 100 pounds assume a volume of 1,200 cubic feet, we may easily calculate the quantity of air required for consuming a certain quantity of fuel. Wood, turf and stonecoal, contain a certain quantity of oxygen; this of course must be subtracted from the quantity of atmospheric air. It has been ascertained at blast furnaces, that, when the quantity of fuel used during twelve hours in pounds is divided by 5, it shows the number of cubic feet of air required in one minute. Thus, when a blast furnace is to consume twenty charges of charcoal, of 15 bushels each, during twelve hours, and the charcoal weighs 20 pounds per bushel, the quantity of air which must be furnished to the furnace in each minute, of atmospheric density, is $\frac{15 + 20 \times 20}{5} = 1200$ cubic feet.

Regulators of Blast.—Piston blowers do not form a blast of uniform density; but as this is, in most cases, of the utmost importance, particularly in blast furnaces, regulators are attached to these machines. Regulators consist of two classes, which are of constant or variable capacity; the latter are termed wet and dry regulators. We object utterly to all wet regulators, for the same reasons that we objected to wet blast machines and damp air. A regulator of variable capacity has been shown in fig. 186; it may be constructed of iron or of wood; the principle in either case is the same. These regulators are not perfect; nor do they produce such uniform density as is generally required at blast furnaces. Practice has shown this defect, to which theory points very distinctly. The weight of the movable piston, and the balance weight, are always great in these variable regulators; and as that weight is constantly kept in an upward and downward motion by each stroke of a piston, the force of impact must always be overcome in every change of the machine; this of course will never admit of a uniform density in the blast. We are, therefore, reduced to the dry regulator, with constant capacity for a uniform blast. These regulators, which are mere chambers, have been constructed both above and below ground, and of stone, wood, or iron; and in a cubical, oblong, globular, and cylindrical form. At present this subject is so far settled that sheet-iron right cylinders, of from 4 to 8 feet in diameter, and from 15 feet to 40 feet in length, are generally adopted as the most suitable and best forms. The thickness of the sheet-iron is not often more than $\frac{1}{8}$ of an inch, frequently less; the heads are formed of cast-iron, or of sheet-iron and stiffened by wood and iron screws. This chamber, or regulator, is provided with a safety-valve, to insure it against bursting from excessive pressure. The blast is introduced at one end, and tapped at the same or the opposite end. The equalization of the blast is produced by the elasticity of the air. It is easily understood, that in a large chamber the pulsations of the blast machine are not so strong as in a small one, but the size must be limited for reasons of economy. As a general rule, it is established that the capacity of this regulator should be from 10 to 18 times that of one of the blast cylinders; but harm ensues if it is larger. For charcoal furnaces it should have a capacity at least 20 or 25 times that of the cylinder; it may be smaller for anthracite and coke furnaces.

Necessity of Uniform Density.—This subject deserves more attention than is generally bestowed upon it. In former pages we have endeavored to explain the manner in which flame may be produced from fuel that is without flame, by dividing it by strong draught or blast. The dense air has a twofold action upon fuel; first, chemical, by bringing the particles of air and fuel into close, quick contact, and causing a rapid union of the two; and second, mechanical action, in driving a large quantity of heat through a limited space. In smelting ore in a blast furnace, it is necessary to consume the oxygen of the air as quickly as possible; but as the ore consists of oxygen and metal, the carbon of the carbonic oxide would be soon consumed, and the operation reduced to a comparatively small space, so that all the reducing of ore would be performed near the tuyere. This is actually the case when the blast is too weak for the fuel. Ores which are easily reduced, such as lead, copper, and bog ores for iron, may be smelted on this principle quite advantageously; but it is not so with refractory iron ores. In order to raise or increase the space in which reduction is performed, we introduce a blast of more or less density, according to the refractory character of the fuel. The velocity imparted to the particles of air, causes small particles of fuel to separate from the larger masses, and thus supply the higher parts of the hearth or crucible in a furnace with very combustible hot carbon, which may unite with the oxygen liberated from the ore, and make up the deficiency which cannot be furnished by coarse fuel, because the latter is too cold and not in so close contact as is required for a lively combustion. Thus, carbonic oxide is supplied for reduction through a high column of oxidized ore, and in the mean time a lively combustion is produced which affords the necessary degree of heat for deoxidation. Hence, it is evident that soft fuel cannot bear so much pressure of blast as hard, and the density must be necessarily limited to the degree of hardness of the coal. The size of the particles of carbon thus torn loose and carried through the ore must also be limited, and the smaller they are so much the better is their effect. Large particles will settle in the wide parts of the furnace, and obstruct the free passage of the hot gases. We find, therefore, in using too strong blast, that a furnace can be choked by coal dust. Thus, if a certain density is required for a certain kind of fuel, it follows, that that density ought to be uniform. If the pressure is less than that suitable for the coal, it will not produce the desirable effect; and in case heavy particles of coal are in motion, their motion or velocity must relax, and they be deposited. If the oscillations of the blast are too strong at the time when the densest air passes into the furnace, the particles of coal which are separated by it at the tuyere cannot move on, because the succeeding relaxation of pressure causes them to settle. The effects of an oscillating blast are similar to those of too strong a blast. It is therefore more advantageous to relax the excessive density by a valve, in case it cannot be equalized by a regulator, than to bring it into the furnace; for nothing is more injurious to the smelting operations than dust deposited in the wide, or any other, part of the furnace.

Pipes and Nozzles.—The air condensed in blast machines is conducted in pipes to those parts of the smelt works where it is required. The material of which pipes are made is tin-plate, copper, sheet-iron, cast-iron, or wood. Wooden pipes are generally square channels, and cannot be used where a dense blast is to be conducted. Tin-plate pipe is most frequently used for centrifugal blowers and those machines where the pressure is not carried beyond ¾ of a pound. Sheet-iron, or cast-iron pipes, are employed for blasts of higher densities. These pipes are frequently laid below ground, which is the best place, provided they are accessible at any time, and are deposited in channels with walls of stone, so as not to be injured by the pressure of earth. As long pipes suffer a considerable extension and contraction, in consequence of the changes of atmospheric heat, they should be bedded upon iron or wooden rollers, and provided occasionally with a knee, which admits of their motion. When the straight lengths are so great that there appears to be danger that the pipe will break, a compensation-joint is inserted; this frequently consists of an end of a pipe movable in a stuffing box. The plan represented in fig. 194 is preferable to it. This is a compensation-joint, consisting of two round dishes of sheet-iron, or copper, 20 or 30 inches in diameter, according to the size of the pipe, riveted air-tight at their periphery, and

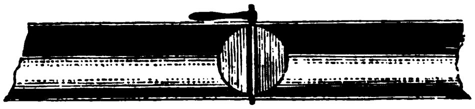
FIG. 194.



screwed to the two flanges of joining pipes. The sheet-iron may be from $\frac{1}{8}$ to $\frac{3}{16}$ of an inch thick. The large diameter and flexibility of the sheet-iron allow the two pipes which are joined to it to move longitudinally, independent of each other.

The capacity, or diameter of the pipes, is as the square root of the quantity of air which is to pass through them. A pipe of 10 inches in diameter, and which is smooth inside, is considered sufficient for conducting 1000 cubic feet of air per minute. A pipe, therefore, which is to conduct 4000 feet per minute must have a diameter of 20 inches. The laws which regulate this subject are somewhat complicated; but we may assert that a blast pipe is never too wide; and if considerations of economy do not determine the limit of the diameter of a pipe, the higher expenses incurred in a wide one are quickly repaid by better work in the furnaces, and by the saving of the power which drives the blast machine. Flexures, or knees, should be avoided by all means in air-conducting pipes. If these cannot be dispensed with, the curves should be gentle, and the pipe wider at such places. Where a blast is conducted from a main, or where the main is divided into branches, each branch should be provided with a valve, so that the communication can be stopped at any time when it is required. Complicated valves are of no use. A simple thrundle-valve, such as is represented in fig. 195, is in all cases sufficient for the purpose. The winch should be parallel with the pipe when the valve is open, and cross it when shut. In some cases, particularly in forges, the valve handle is provided with an index which marks the degree of opening in the valve, and by this means the quantity of the blast which passes is regulated.

FIG. 195.



Nozzles are the mouth-pieces of the pipes, which lead the blast into the furnace; these are tapered or conical tubes of 10 or 15 inches in length, and from 1 inch to 5 inches in width. The diameter varies according to the quantity of air which is to pass it. The form of these nozzles is of some consequence to the smelting operations, as well as to the power which drives the blast machine. A nozzle which is much tapered, such as is represented in fig. 196, spreads the air as soon as it passes the point of greatest contraction, which is in that place where the sides of the nozzle, if extended, would cut each other. A nozzle of this kind does not hold the blast together; and is not adapted to work well in blast furnaces, where the full pressure of the blast should reach as far as possible into the fuel. When we reflect on the necessity of destroying some of the fuel mechanically, as we have explained before, we easily comprehend the importance of the form, or taper, of the nozzle. A cylindrical mouth-piece will carry the full pressure of the blast farther than a nozzle of any other form; but it is not necessary, in order to obtain this result, to make the whole length of the nozzle cylindrical. It is sufficient when the cylindrical part of the pipe is as long as the extreme or smallest diameter. A form of nozzle, such as is represented in fig. 197, will furnish a perfectly cylindrical current of blast. Generally, the extremity of the nozzle, of the length of its smallest diameter, determines the form of the current of air; all the other parts of the pipe may be wide or narrow, or tapered, without any influence on it; and as narrow pipes cause much friction, we easily perceive that long nozzles cannot be of any use. The advantages which some smelters and forgemen profess to find in a particular length of nozzle, exist only in fancy. But the form or taper of the mouth is certainly of great influence in all metallurgical operations. Fixed rules for the taper of nozzles and tuyeres cannot be established. There are so many conditions bearing upon this form, that it will be always a practical question; but we will refer to the most striking points which have an influence in the case. Hard coal requires a more cylindrical nozzle than soft coal, because more pressure is needed to destroy it, and a compact current augments the effect of pressure. A blast furnace with a wide hearth, requires a more cylindrical form of mouthpiece than a narrow hearth, for the undecomposed air ought to reach farther into it. For refractory ores the nozzle should have

FIG. 196.

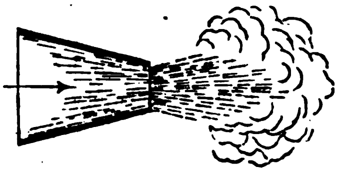
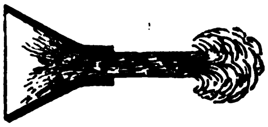


FIG. 197.



less taper than for ores which melt readily; and blast furnaces which are required to furnish a large quantity of metal, should have cylindrical nozzles. Soft coal ores which are easily melted, and those which cannot bear much heat, or whose metals are volatile, forge fires, bloomery fires, and all fires which perform oxydizing operations, work to advantage with tapered nozzles. The interior of the extreme part of the nozzle ought to be polished smooth, so as to form a smooth current of air, and occasion as little friction as possible.

The quantity of air which passes through a nozzle depends very much on its taper, its length, and its smoothness: laws similar to those which regulate the efflux of water, regulate the efflux of air. If we assume a taper of 12 degrees, and a length of the nozzle not much greater than the diameter of the aperture, with a smooth inside, then the following table indicates nearly the quantity of blast which passes through the annexed aperture:

Pressure of Blast.	Quantity in cubic feet for 1 inch diameter, per minute.	Weight in pounds per minute.
½ oz. avoirdupois	18·54	1·43
1 "	26·20	2·02
2 "	36·97	2·86
4 "	52·07	4·07
6 "	63·51	5
8 "	73·04	5·80
10 "	81·83	6·51
12 "	88·74	7·16
14 "	95·47	7·76
1 pound	101·66	8·33
1¼ "	112·78	9·38
1½ "	122·61	10·36
1¾ "	131·44	11·27
2 "	139·48	12·14
2½ "	153·70	13·77
3 "	166·01	15·30
3½ "	176·88	16·75
4 "	186·58	18·15
4½ "	195·35	19·50
5 "	203·32	20·82

Having ascertained the actual pressure of the blast by the manometer, and measured the diameter of the circular nozzle, the first column of the table is resorted to for pressure, and the second and third for quantity; and as the areas of circles are as the squares of their diameters, the quantity of the air which passes must be as these squares. Thus, if the pressure is 8 oz., or ½ lb., the quantity which passes through 1 inch is 63·51 cubic feet; if the nozzle is 1½ inch in diameter, the quantity will be $1{\cdot}5^2 \times 63{\cdot}51 = 142{\cdot}89$ cubic feet; if the nozzle is 1¾ inches, the quantity is $1{\cdot}75^2 \times 63{\cdot}51$; and if 2 inches in diameter $= 2^2 \times 63{\cdot}51$. We do not say that this is exactly the quantity which passes an aperture of that size, but it approximates it.

Tuyeres.—These are substitutes for nozzles, and so far as relates to the quantity of air and the form of current, the same remarks which have been made above, respecting nozzles, are applicable to them. In fact, the tuyere is but an interrupted prolongation of the blast pipe, a mouth-piece which is not directly connected with the pipe. The necessity of giving the current of blast a varied direction in many smelting operations, and at forges and bloomery fires, and of removing concretions at the point of contact between the air and fuel, and the fact that mouth-pieces are frequently burned and must be changed, make it important to separate the termination of the blast pipe from its main body. The form of these tuyeres is varied according to the furnace, fuel, ore, pressure, and some other conditions; thus each case depends upon its own circumstances, and is entirely subject to the experienced views of the operator. The shape, material, and position of the tuyere are of vast importance in all metallurgical operations; they require the closest attention of the practical man. In some cases, such as at cupolos, no tuyere is used, the nozzle is pointed directly into the fuel. In others, the aperture in the hearth-stones of a smelting furnace, is lined with silicious fireclay, which has been made tenacious by mixing or kneading, and the shape, direction, and size of the tuyere is given by the smelter, according to his own judgment. The clay tuyere has its advantages; it works very hot, and may be altered at any time to suit circumstances; it is good for experimenting, but it should not be used in a well-regulated furnace, for it is too liable to changes, and consequently causes fluctuations in the interior of the furnace. Permanent tuyeres are frequently composed of gray cast-iron; white cast-iron and wrought-iron do not endure, because the heat and oxygen, in the presence of the silicious matter from the hearth and ore, soon destroy it. These iron tuyeres require frequent renewal, and are in no respect superior to those of clay in smelting operations; in forges, their use is not so objectionable.

The only practically good tuyeres are the copper tuyere and the water tuyere; the former is used exclusively with cold blast, and the latter with either cold or hot blast. A copper tuyere has in some cases its particular advantages; it works hotter than a water tuyere, and may be easily moved so as to make it suitable to the varied conditions in smelting operations. The form of a tuyere is sometimes round, like the nozzle, but in many instances one half of it is flattened, so that it assumes the form of a capital D placed horizontally, thus, ⌓. This form is given to admit the moving of the nozzle on its flat or under part. Such a tuyere and nozzle are represented in fig. 198. The tuyere is generally thicker at its narrow part than at the wider portion. The thickness at the mouth is generally from $\frac{1}{2}$ an inch to $\frac{3}{4}$ of an inch, and $\frac{1}{8}$ to $\frac{3}{16}$ of an inch at the wide part. The nozzle, as represented, is joined to the blast pipe by a leather bag, or hose, so as to be movable on the flat bottom of the tuyere, and be directed as the smelter chooses; this is particularly necessary in bloomery and forge fires; and in iron smelt furnaces where a particular kind of cast-iron is to be made. The direction of the nozzle must always be such that the tuyere may absorb all the blast which is furnished by it. For cold blast, copper tuyeres are sufficiently durable; the silicate of copper which may be formed is not very fusible, and as copper is an extremely good conductor, it will resist for a long time the strongest heat of a smelting furnace, provided the tuyere is not too wide to be cooled by the blast. A narrow copper tuyere may last six months and longer, in a smelting furnace.

FIG. 198.

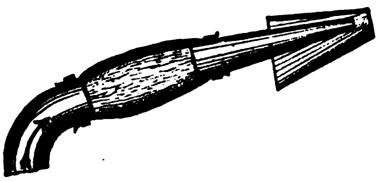
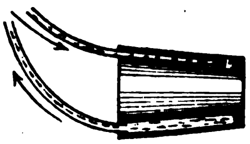


FIG. 199.



For hot blast or cold blast in forges, neither of the above-mentioned tuyeres is suitable. Whatever may be the material of which a water tuyere is composed, it is made hollow, to admit of the free circulation of a current of cold water. In fig. 199, a round water tuyere is shown, such as is commonly used in iron furnaces. The body of it is hollow, and either cast in one piece, or if in several, they are riveted, or soldered, or welded together. The mouth of the injection pipe for the water ought to pass near to the narrow part of the tuyere, where the heat is greatest, and thus furnish cold water where it is most needed: this pipe enters at the lowest part of the tuyere, and the heated water flows off at the highest point. For forges, and run-out fires, the tuyere is generally provided with a flat bottom, which is solid; the water is admitted only in the upper, or circular part of it. In practice, we find tuyeres of a great variety of forms, all calculated to impart durability, because these instruments are expensive, and suffer a great deal from heat. Water tuyeres are generally made of iron; but the remarks respecting their use for cold blast, are equally applicable here. The copper tuyere is the cheapest and most durable.

In working hot blast, the nozzle is generally fitted closely into the tuyere which thus forms both nozzle and tuyere. This interferes with the cleansing of that part of the aperture which is close to the fuel; but, as this is necessary to be done, the following method is resorted to, in order to remove those cold slags, and lumps of ore which may happen to settle at the place of the cold metal. It is shown in fig. 200. The blast pipe forms a knee as near to the tuyere as possible; and in this angle there is a hole of about 1 inch round, usually closed by an iron stopper fastened to a small chain. A round iron rod, of ¾ inch iron, A, long enough to reach into the furnace, is passed through the hole, and any clinkers which may have gathered at the point where the blast enters, are removed, by pushing them into the furnace. In this case, there cannot be a movable nozzle, nor would one be of any use.

FIG. 200.

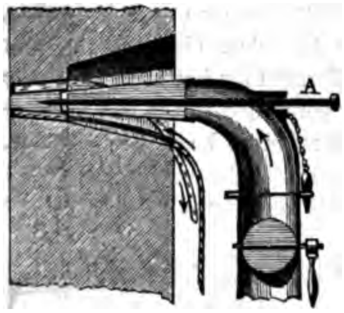
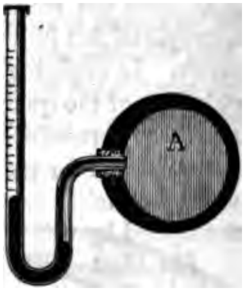


FIG. 201.



Manometer.—This instrument, which is represented in fig. 201, consists simply of a glass tube, of $\frac{1}{4}$ or $\frac{3}{8}$ inch bore, bent in the form represented. The long leg may be 10 or 12 inches in length, and open at the top; the short part is about 6 inches in length. This is bent so as to be fitted by means of a cork stopper to the blast pipe A. In the angular lower part, is mercury to the height of a few inches, which prevents the passage of the dense air from A, through the tube. But, as the mercury is fluid, and movable, the blast will drive it up into the long part of the tube; and the height to which it will rise indicates the density of the blast. Each inch in height which the quicksilver rises, is equal to one pound of pressure to the square inch; and if we fasten a scale, which may be made of strong paper, or Bristol board, to the glass tube and divide it into inches, commencing at the surface of the mercury when at rest in the long leg, we obtain at once on the scale the pressure in pounds, and parts of a pound. One inch of quicksilver in the barometer is equal to half a pound of pressure; but, as the mercury sinks in the short branch, equally as much as it rises in the long one, the measure pointed out in the latter must be multiplied by 2, which makes every inch equal to one pound.

In using this instrument for measuring the density of blast, it should be put as close to the nozzle as possible. And as hot air will destroy a correct measurement, it is sufficiently cooled before it touches the mercury by interposing an iron or metal tube, of a couple of feet in length, between the blast pipe and the manometer. In applying the densities formed for hot blast, to the calculations of the quantity of air, as contained in the last table, the necessary corrections for temperature must be made; and, since gases expand for each degree of heat $\frac{1}{493}$, the results obtained by using the table, assuming that it is calculated for 32°, must be multiplied by this number.

Hot Blast.—When air is heated before coming in contact with fuel, it will cause a saving of the fuel, in the same proportion that its own temperature bears to that which is generated by its combustion; but as the quantity of heat thus gained is extremely limited, and as the apparatus for heating air is expensive and troublesome, hot air or hot blast is not much used in the common operations. It has, however, a quality which makes it desirable in smelting operations, particularly of refractory ores. It combines with carbon with greater facility than cold air, and forms carbonic oxide in a shorter time. And, since the most perfect neutralization of oxygen, is of great importance in reducing metallic ores, the use of hot blast affords advantages of an economical kind, which amount in some cases to considerable gain. We shall not dwell here on the consideration either in favor of or against the use of hot blast, but postpone their notice to the next part of this book, merely pointing out here the means by which hot blast is obtained.

The apparatus by which air is heated, has been variously altered since its first introduction to aid smelting operations. Blast has been heated in horizontal cast-iron pipes, but these were not found to be durable; nor do vertical pipes secure the desired effect. We shall not allude to the innumerable varieties of other forms, as they are not worthy of attention. The subject at present is so far settled, that inclined pipes with a vertical draught of the fire by which they are heated, are regarded as the most approved form for a hot blast apparatus. Fig. 202 shows the vertical section of the furnace, with its pipes of cast-iron. The length and number of the pipes vary according to the quantity of air to be heated. The two horizontal pipes, A B, are generally from 12 to 18 inches in diameter; round, oval, or constituting half a circle in form. The length of the upright pipes varies from 4 to 10 feet in length, and from 4 to 6 inches in diameter, according to the size of apparatus. In fig. 203 is a transverse vertical section of the same stove. We observe here the position of the pipes A

FIG. 202.

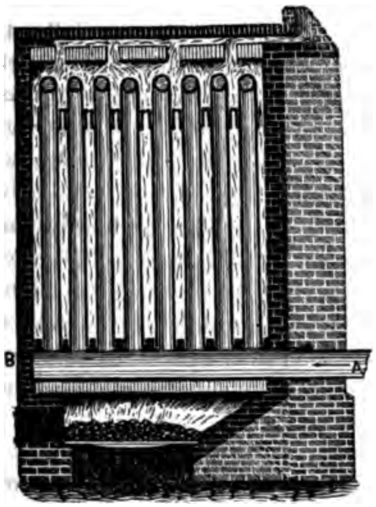
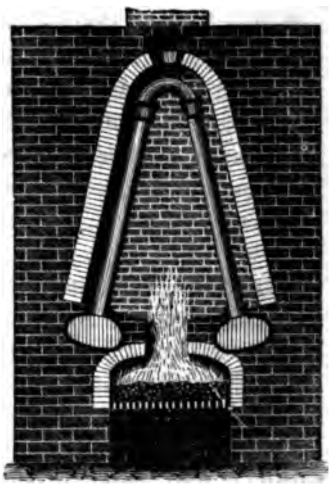


FIG. 203.



and B, into one of which the cold air is conducted, while the other conducts the hot air to the furnace. The angle at which the upright pipes meet is arbitrary; still it should not be too obtuse nor too flat, for they sometimes are heated red hot, and then are liable to bend, or even to break. In the vertical position, such accidents are prevented, but more fuel is required to heat them. The horizontal pipes A and B are walled in for their entire length, to prevent injury to them by heat.

As we have already remarked, the size of the apparatus depends on various circumstances; it is not, therefore, possible to establish a rule for the number or the size of the pipe. The total surface of the heating pipe, that is, the vertical pipes with their semicircular caps, is in proportion to the quantity of air and the degree to which it is to be heated. It has been ascertained that 100 square feet of surface will heat 1,000 cubic feet of air to 300° per minute; but for twice that degree of heat more than twice the extent of surface is required. At the top of a blast furnace, where blast is heated by the waste heat, a greater surface is required, because that flame is not so hot as one generated directly from fuel; and it likewise carries solid matter which settles on the pipes and thus causes a loss of heat. An apparatus should have ample size, if waste heat is employed to heat it. Where solid fuel is used, the fire may be urged if necessary, and more or less heat conducted to the pipes, as circumstances require.

In general we may remark, that all hot blast apparatus must be so arranged, as to admit either hot or cold blast to be used at the furnace. The hot air apparatus should be as near the tuyere as possible; partly because heat is lost by radiation, but chiefly because the hot air causes more friction in the pipes than the cold air. The pipes should not be too large in diameter, and the flame so directed, that it meets the pipe under an obtuse angle with its axis. The pipes must be accessible from the exterior of the stove to admit the removal of ashes which may adhere to them. The joints, which are faucet or spigot joints, muffs, must be well secured by good cement, which causes them to be air-tight, and resists heat. Iron cement may be composed of 5 parts iron borings, and 1 part fine clay, moistened by vinegar; or, 60 parts of borings, 1 part sal ammonia, and 6 parts clay, the whole moistened by water. To this mixture, sulphur is sometimes added, which is of no use, and should not be in excess in any case. Whatever may be the kind of cement used, the pipes should not be heated until it is thoroughly oxidized.

Blast Machines.—These investigations must have rendered it apparent what kind of blast machines are to be selected for any particular smelting operation. The first question to be settled, is, How much blast and what degree of pressure is required? When it exceeds ¾ of a pound, iron cylinder bellows must be used. A wooden cylinder machine may serve for ¾ of a pound pressure and less. When less than ½ a pound will answer, no machine furnishes a better blast than the centrifugal blower. The quantity of blast made per second is found by multiplying the velocity by the surface of the piston in feet, and this result by ¾, or ½, according to the kind of machine. Considerations of economy here are in the wrong place. We may save anywhere else, but not at the blast machine. A water regulator, or a machine where air can possibly be moistened, must always be rejected in any smelting operation, where oxides are to be reduced. These machines are never useful anywhere.

It would lead us too far, and extend this treatise to an unreasonable length, if we should allude, in this general description, to particular niceties in metallurgical operations, even if such are of a general application. In the third part, we shall mention such particulars as they occur.

PART THIRD.

PARTICULAR METALLURGICAL OPERATIONS.

CHAPTER I.

What are Metals?—Chemists denominate as metals those substances which are combustible, that is, which liberate heat in combining with other matter: they assert that metals are good conductors of heat and electricity, and may be polished; are fusible and opaque; heavy, malleable, and ductile, &c. These are all vague definitions; for not one of the metals answers perfectly to this description. Gold may come most completely within its compass, but if it possesses all the other particulars, it certainly is not combustible in the common sense of the term; while potassium, an equally beautiful type of metal, is extremely combustible and not heavy. We really do not see any reason why all solid substances which are not oxidized should not range with this class of matter. There cannot be any objection to calling carbon a metal; and we do not see why sulphur is less a metal than selenium or arsenic; why phosphorus is not denominated a metal as well as calcium; both are almost equally combustible, and if phosphorus has no metallic lustre, that is merely indicative that it is not condensed into so narrow a space as calcium. Phosphorus is more volatile than most of the other metals; but no metal is as permanent as carbon, and still the latter is not recognized as a metal. We do not see the slightest objection to calling hydrogen a metal; it possesses almost all the properties belonging to metals. But when matter, gaseous or fluid at common temperatures, is excluded, there cannot be any objection to calling all solid elementary substances metals. Silicon so much resembles a metal in all its properties, that its exclusion cannot be justified, and most philosophers range it with the metals. It is very much questioned whether metal sare not compound matter; but as this point does not interest us, we allude to it merely in support of the above pretensions.

In order that we may not appear arbitrary in our classification, we submit to the usual one, and exclude from our investigations all matter which is not considered a metal by common consent.

Classification of Metals.—The number of metals which are regarded as useful, is very limited. But, as many which are of no direct, practical use, enter into combination with those which are generally useful, it is necessary to allude to some of the former, although their interest arises solely from their combination with others. In entering on this part of our work we are under the necessity of classifying the metals in some such manner as shall be useful to the smelter. The most rational classification appears to be founded upon the relation of metals to oxygen, supposing that the reduction of oxides is effected by means of carbon. The number of elements which form minerals is sixty-two, all of which have more or less influence in metallurgical operations. About fifty of these elements are considered metals by chemists, of which nearly half the number are found in such large quantities as to be of importance to the smelter. A large number of metals form slags, as oxides or other compounds, and are hardly known in their pure condition: still these are of high interest, not only because they form slags, but because these slags invariably impart a peculiar quality to the metal which is smelted under their influence. We may, therefore, divide the useful metals into two groups, the one which forms chiefly slags, and the other chiefly metals. To the first division the following belong, viz.: Potassium, Sodium, Calcium, Magnesium, Manganese, Aluminum, Selenium, Titanium, Tellurium, Arsenic, and Chromium. The second group will then consist of Zinc, Cadmium, Iron, Nickel, Cobalt, Antimony, Lead, Bismuth, Copper, Mercury, Silver, Platinum, and the Platinum metals, and Gold.

Instead of describing the general qualities of metals, which we assume to be known by our readers, we insert the following table, which furnishes all the information of this kind which is here required.

Names.	Color.	Specific gravity.	Fusibility.	Malleability.	Volatile at	Decomposing water.	Decomposes
Potassium	gray-white	·865	136°	like wax, brittle at 32°	red heat	any temperature	all minerals
Sodium	"	·972	194°	malleable at 32°	"	"	do. except potassa comp'nds
Calcium	"			"	"	"	"
Magnesium	white		red heat	"	"	red heat	"
Manganese	gray-white	5·85	high heat	brittle, soft		any temperature	"
Aluminum	white		"	malleable		decomp. air at red heat	"
Selenium	red-brown	4·3	212°	very brittle	red heat	"	
Titanium	red	4·3	infusible	"		"	
Tellurium	gray-white	6·1	600°	"	red heat	"	
Arsenic	gray	5·7	400°	brittle	356°	any temperature	
Chromium	"	5·9	high heat	"		very permanent	
Zinc	white	6·8	770°	malleable	white-heat	at 400°	
Cadmium	"	8·6	550°	"	600°	burns in air	
Iron	"	7·6		"	very high h.	at any temperature	decom. the following
Nickel	"	8·2		"	"	"	"
Cobalt	gray	8·5		brittle	"	red heat	"
Antimony	white	6·7	932°	"	white-heat	permanent	"
Lead	"	11·3	594°	malleable	"	"	"
Bismuth	white-yellow	9.8	476°	"	"	"	"
Copper	red	8·8	1996°	"	high heat	"	"
Mercury	white	13·5	39°	"	680°	"	"
Silver	"	10·4	2000°	"	high heat	very "	"
Platinum	blue-white	21·2	very high h.	very malleable	very high h.	" "	"
Rhodium	gray-white	11·	melts in saltpetre	brittle	"	" "	" "
Iridium	"		high heat	malleable	"	" "	"
Osmium	blue-black	10·	"		"	heated in air	"
Palladium	blue-white	11·3	"	"	"	high heat in air	"
Gold	yellow	19·4	2200°	very malleable	moderate h.	permanent	

All the metals, with few exceptions, are remarkable for a high and peculiar lustre; they conduct heat and electricity better than any other substance. They are considered as opaque, but this can be no absolute property, for all metals are porous, and consequently must transmit light when in a body sufficiently thin. The affinity of metals for oxygen is remarkably strong; but under certain conditions, the oxygen is removed by chlorine, sulphur, and other substances. The compounds which are of interest to the metallurgist, are the oxides, carburets, sulphurets, phosphurets, chlorides, arseniurets, silicides, &c. The salts of the metallic oxides are, however, of the most interest,—such as silicates, carbonates, phosphates, chlorides, &c.

Affinity for Oxygen.—Metals are, generally speaking, combustible. They generate heat under the same laws as carbon and hydrogen. It makes no difference in the quantity of heat generated, whether we burn zinc with a pound of oxygen, or carbon with the same weight of oxygen. But, while potassium burns on water, gold must be combined with chlorine before it can be oxydized, that is, its affinity is so feeble, or its body so compact, that it must be dissolved, or divided, into the most minute atoms before it can be combined with oxygen. The metals never combine with any oxydized substance, and least of all with their own oxides, however determined their affinity for oxygen may be. To this rule the exceptions are very few. This is one of the most important peculiarities of metals; and it is the best auxiliary to the smelter. This want of affinity for other substances is the reason why fluid metals appear with a convex surface. The same property is strikingly shown in the refining of precious metals on the cupel; it is the cause of fibres in wrought-iron. The form under which metals most readily oxidize is of high interest; but as it depends upon many circumstances besides affinity, we will point out the means by which they are deprived of oxygen, from which the reverse may be deduced. Metals which are deprived of their oxygen by the mere application of heat, are—Mercury, Silver, Gold, Platinum, Palladium, Rhodium, Iridium, and Osmium; for this reason these are termed precious metals.

Those metals which retain their oxygen at high temperatures, and in fact cannot be reduced by heat only, we shall proceed to enumerate. Of the number, the alkaline metals, Potassium, Sodium, Calcium, and Magnesium, decompose water at any temperature and retain their oxygen at any heat, while their oxides form alkalies in all cases.

Aluminum and similar metals retain their oxygen, but do not decompose water except at high heats, and form either alkalies or acids.

Nickel, Cobalt, Iron, Tin, Cadmium, Zinc, and Manganese, decompose water at a red heat, and their oxides form either alkalies or acids, according to the matter present, or their state of oxidation.

Lead, Copper, Titanium, Bismuth, Uranium, and Tellurium do not form acids at high heats, and do not decompose water at any heat: neither does Antimony, Chromium, or Arsenic, but when oxidized, they form invariably acids at melting heats.

The combinations of oxygen and metal take place in certain definite proportions, and, so far as relates to most of the metals, in various definite quantities. There is only one oxide of aluminum, but there are three of iron which interest us. The protoxide of iron is a strong alkali, the magnetic oxide a feeble alkali, and the peroxide is more of an acid than an alkali. Peroxide and protoxide of iron, both infusible by themselves, form a fusible slag, or glass. Arsenic forms in all stages of oxidation an acid, which never melts together with another acid, or a highly oxidized metal. The electro-positive or negative character of an oxide, is however no condition required for its fusibility; for litharge and lime, both strong alkalies, melt together and form slag. But it is always a requisite condition that one of the constituents must be fusible, in which the other is merely suspended. This chemical relation is by no means limited, that is, one and the same substance is not always, nor in all relations, of the same character. The oxides of iron are always alkalies with silex, but they are acids in relation to oxide of lead. Alumina is an alkali in the presence of silex, but an acid when in contact with the alkalies proper. The study of the metallurgist must be directed to these chemical relations, and chiefly also to the degree of fusibility of these compounds, and the relation which they bear to the metal to be produced under their influence. As a rule, we may state, that the compounds of single equivalents of metals and oxygen always constitute a base, or alkali, and that any more oxygen destroys that property. Thus, the protoxide of manganese, Mn. O., is a strong basis, and precipitates the protoxide of iron from a slag, or any compound; but the peroxide of manganese, Mn. O_2., is driven out by the protoxide of iron. When carbon is present, one atom of oxygen is absorbed by it, from the peroxide of manganese, and the iron is again driven from its union.

Hydrated Oxides.—The oxides also combine in certain proportions with water, and form definite compounds, called hydrates. These combinations are not only of interest so far as they form the most porous and best kinds of ore, but the tenacity with which water adheres to some of the hydrates is remarkable. Potash, clay, and silex, retain their water at an almost red heat, and the first may be actually melted without losing all its water.

The degree of affinity of oxygen for metal is the strongest, and is most difficult to destroy at a medium state of oxidation between the highest and lowest. Protoxide of tin is easily converted into metal, so is peroxide, but the sesqui-oxide, a combination between, or of, the two, cannot well be reduced to metal without evaporating the largest part of the metal. In practical operations we always endeavor to smelt the highest oxides, and convert the ores into them, in case they are not naturally in that state. The reasons for this, are the following: in reviving metals from their ores, it is not only the object to remove the oxygen from the metal, but also to produce so high a heat as to melt the metal at the precise moment when the oxygen is removed. If only little oxygen is combined with the metal, it is evident that but little heat is produced; the metal may be in the proper form, but it cannot accumulate into a body, and the least amount of oxygen will oxidize. it again. If the quantity of oxygen is large, a proportionate amount of carbon will be consumed and the heat will be higher than when there is less oxygen with the same amount of metal; the metal will now melt, agglutinate, and in that form resist the influence of oxygen successfully. This law is apparent in most cases when smelting is done on a large scale, but particularly so in smelting refractory metals,—such as iron, manganese, chromium, and others. Lead may be smelted in either form, because the metal is very fusible, but less lead is evaporated in smelting minium than litharge, or galena.

Affinity for Chlorine.—Chlorine has a peculiar tendency to induce metals to crystallize; it causes fluidity and brittleness. The affinity of chlorine for metal surpasses that of oxygen, and drives out the latter in all instances. It cannot be removed by carbon, but it sometimes may be by hydrogen, as in the case of gold, silver, copper, lead, and mercury. The energetic connection between chlorine and metals, would be an impediment to working ore, in which even a small amount of it was present; but, all chlorides are extremely volatile and easily driven off. Still there is always an indication of the presence of chlorine in those metals which have been smelted from ores containing it. Chlorine removes all other matter from metals, when the latter are in a state of fusion; carbon, sulphur, phosphorus, and other volatile matter is driven off by it, and, if the heat is continued, the chlorine itself escapes at last with a portion of the metal. This is the case when only a minute amount of it is present. It is, therefore, one of the most powerful means of purifying metals. Lead smelted from chlorides, or only from a mixture of chlorides and other ore, is always purer than that from oxides or sulphurets. The proper application of chlorides has a most beneficial influence on smelting and refining operations. Zinc does not combine very readily with iron, but if some chlorine is in it when melted, the operation is performed with the greatest ease. Chlorine has a remarkable tendency to combine with metals, and is particularly distinguished for removing oxygen from the peroxides; it, therefore, purifies the surfaces of melted metal, and causes those in an alloy to unite closely. This is not only the case with different metals, but also with any one in which there is chlorine.

Chlorine is not decomposed by any heat, or other means; it is, therefore, always present in its pure and proper form, and we may depend upon removing it finally, by the continuation of heat only. All metals which have been smelted under the influence of chlorine are remarkably inclined to oxidize so long as it is not entirely removed. It is a harmless substance to the metals; and, as it is a powerful means of fluxing ore and slags, and causing metal to be fluid, its use ought to be more extended than it is at present. So long as volatile substances are combined with a metal, very little or no chlorine escapes; but after sulphur, phosphorus, and similar matter is driven off by it, chlorine itself escapes—first with arsenic, then tin, antimony, mercury, zinc, and iron. We may therefore regulate the refining of metals under the influence of chlorine, according to the volatile character of the substance to be removed; observing due regard to the degree of affinity between chlorine and that substance. Some chlorides escape in their proper form, such as those of arsenic, tin, and antimony; others are decomposed so soon as they are liberated and atmospheric air or steam has access, as chloride of iron, aluminum, and silex, which are converted into oxides and hydrochloric acid. All evaporated chlorides may be recovered by condensation; they are precipitated at a temperature a little higher than that at which steam condenses.

Iodides, bromides, and fluorides, are similar in operation to chlorides; but as they are not so plentifully met with as the latter, they are of little interest to the smelter.

Sulphurets.—All metals combine more or less vividly with sulphur, which combination is, in all cases, destroyed by oxygen or chlorine, with the assistance of heat. Sulphurets are formed when sulphur is brought in contact with hot metal, provided no oxygen or chlorine is present. When oxides are heated with sulphur which so far predominates as to absorb all the oxygen in forming sulphurous acid, the remaining sulphur will combine with the metal. When sulphates are heated in the presence of carbon or hydrogen, the oxygen of the sulphuric acid is abstracted, and sulphurets remain. Sulphuretted hydrogen, when conducted over oxides, or over red-hot metal, forms sulphurets. A hot, or fluid metal, which contains only a small amount of chlorine, does not absorb sulphur. The chemical relation of sulphur to metal is similar, in respect to quantity, to that of oxygen; that is, the number and equivalent composition of the sulphurets, correspond with the number and equivalent of the oxides, of the respective metals. Sulphur causes metals to be more fluid, and brittle when cold, and, in most instances, imparts to them a pasty condition which impairs their ductility when hot. A large quantity of sulphur causes a low degree of fusibility in metals, which is shown most distinctly in the sulphurets of antimony, lead, copper, and iron. This fusibility decreases more rapidly than the evaporation of sulphur. Iron pyrites melt at a very low red heat; but when the quantity of sulphur is reduced by evaporation to half the original quantity, it requires a strong white heat to melt the sulphuret. This fusibility of the sulphurets is, in many instances, judiciously applied in the formation of a fluid slag. For the removal of sulphur from metals, the presence of free oxygen or chlorine is required; it is, therefore, of no avail to melt metal which is adulterated with sulphur, under an alkaline slag, because no slag will absorb sulphur from a metal until it has itself been converted into sulphuric acid. Sulphur cannot be removed entirely when carbon is present, or hydrogen, or any reducing agent; it requires an oxidizing influence, and a thorough exposure of the metal to oxygen. Sulphurets may be reduced by means of metals which show a stronger affinity for sulphur than those in combination with it. The sulphurets of copper, lead, antimony, and others may be reduced by iron, but we never thus obtain pure metals; the newly-formed metal is either adulterated by the absorbent, or by sulphur. Instead of metals themselves we may employ the oxides, particularly the peroxides, finely powdered and mixed with carbon. Sulphurets of antimony, silver, and bismuth, may be reduced by means of hydrogen, but no other metals.

Phosphurets.—Phosphorus combines readily with most of the metals, and adheres tenaciously to them. The combination is readily formed when phosphates—the form in which it is generally found in the ores—are heated in the presence of carbon; and, as the latter is always used in smelting operations, we may reasonably expect phosphorus in any metal which is smelted in the presence of phosphoric acid, and carbon or hydrogen. Therefore the presence of bones, or bone ashes, in an ore or in a slag, will cause the metal to contain phosphorus. The best means for forming a phosphuret is, to heat a phosphate in the presence of carbon. Phosphorus is more easily oxidized than sulphur, and combines in this condition readily with alkalies and alkaline earths; we may, therefore, by these means, remove phosphorus. It also causes metals to be very fusible, more so than any other substance, but disposes them to be brittle when cold.

Carburets.—Carbon has only a feeble affinity for metals, and cannot readily be combined with them. But, in most cases, the metals when reduced from porous oxides, in the presence of an excess of carbon, absorb some of it, and condense it in their pores. It is doubtful if a chemical combination is formed; still, there are indications of legitimate compounds under certain conditions. The best means of forming carburets are the carbonates, and oxalates, heated in the presence of carbon. The crude iron obtained from the smelting of sparry iron ore, may be considered a real carburet of iron. Carbonate of lead, when reduced by means of carbon, forms also a carburet; but this is less distinct than that of iron. In consequence of the faint affinity of carbon for the metals, they are generally very brittle when the amount of it is large. But, when a small amount only is mixed mechanically with metal, as is the case in gray cast-iron, its strength is not much impaired. The combinations of carbon and metal are more fusible than pure metals; and as carbon is easily removed from metal by oxygen, it is one of the best means to cause metals to be fusible.

Alloys.—We shall not here enter fully into the peculiarities of alloys—which shall be done under the particular metals—but we will point out some of their general characteristics. The metallic elements do not, at first sight, appear to combine in certain ratios and form definite compounds; still, it cannot be denied that some metals do; and we are justified, by the general law of affinity, in assuming that all metals combine chemically. We succeed always in melting various metals together, but we do not very often succeed in separating the excess of any one. The cause for this may be either the volatility of one, or more, metals in the alloy, or the refractory nature of another. As a general rule, we may state that all the metals which form alkalies have a particular tendency to unite with those which form acids. Potassium combines readily with antimony and arsenic, more so than with other metals. In considering the nature of protoxides, in their chemical relations, we may successfully form a series in which the ability of metals to combine is represented. This accounts for the peculiarities of the alloys of selenium, arsenic, antimony, and tellurium; which resemble very much the combinations of metal and sulphur, or phosphorus, or chlorine. All these substances form acids in their most simple combination with oxygen. Alloys and compounds of this kind are peculiarly inclined to be brittle and fusible. When two metals are near in the series of affinities for oxygen, they do not combine very readily; and they may often be separated by crystallization only, when their degree of fusibility is sufficiently distinct. This happens when both metals absorb the same, or nearly the same, quantity of oxygen in forming oxide. All chemical combinations liberate heat; silver and platinum, when melted together, produce a high temperature; so do zinc and copper. In most cases, we obtain a mere mechanical mixture of metals in an alloy; this is always characterized by forming distinct crystals with one metal, between which the other is visible. When an alloy is formed, which contains equivalents, no such disconnected crystals are observed. An irregularly composed alloy is a mere mechanical mixture, like wax and fat, and never forms a uniform body of metal; it is of either a granulated or crystallized texture, the latter of which is not compact. Between the crystals of such an alloy, one of the metals is always found in a nearly pure condition. The alloy of iron and silver, in which the silver is mechanically inclosed between the crystals of iron, is an instance of these compounds. Lead and tin combine in certain proportions, and whatever excess there may be of either metal, it is inclosed between the crystals of the alloy. The same is the case with zinc and tin, bismuth and tin—and in fact, with all other metals. The number of definite compounds appears to be very large, and in all cases, a metal is never obtained pure, whenever another is present. In cooling a melted alloy, that composition which is most refractory crystallizes first; and that which is most fluid, is compelled to occupy the spaces between the crystals of the most refractory. Thus, copper and tin are very fusible; but in cooling, copper-tin crystallizes first, and tin-copper last—which latter occupies the spaces between the first. Iron and arsenic are very fusible, but in cooling, iron-arsenic crystallizes first, and arsenic-iron last; the surface of the cooled mass shows a perfect network of bright lines, in regular forms. In all these compounds the first crystallized metal, or alloy, contains some of the latter, and the latter some of the first. When a bar of cold lead is held in mercury, the first absorbs some of the latter, throughout its body; the pores of the lead are filled with mercury—but the mercury in this case contains lead, as well as the lead mercury. When iron is gently heated imbedded in carbon, as is the case in making blistered steel, the carbon penetrates the very heart of the iron-rods; but no iron is imparted to the carbon, because its particles are not movable. By these and similar means the pores of a refractory, solid metal, may be filled with another metal, provided the atoms of the latter are movable. Lead does not readily combine with iron, but if we heat wrought-iron turnings in melted lead, the solid iron will absorb lead. Gray cast-iron will not absorb lead, because its pores are filled with carbon. Borings of cast-iron absorb arsenic readily, when imbedded in arsenious acid and heated; but wrought-iron does not absorb arsenic by these means until carbon is brought in contact with these substances. In properly applying these rules, we may form alloys of the most heterogeneous metals, and in legal proportions. It is extremely difficult to form a definite compound of zinc and copper, or tin and copper; but if we take either the oxides of all these metals, or the oxide of any one, and the metal in small particles, and imbed the whole in carbon—heating it so as not to melt it, although bringing it near its melting point—and then apply the heat gradually and slowly, we are enabled to form definite compounds, which may be melted by a heat which does not evaporate either the one or the other metal. We shall point out the formation of alloys by metals directly, in subsequent pages; but we wish to draw the attention to these facts, because it is often very difficult to form an alloy of a definite composition. Yet as these alloys are the most valuable, we refer to the above mode of forming them.

Fusibility of Alloys.—Alloys are more fusible than the mean temperature, at which the metals melt singly, would indicate. This is a very important law in our investigations, and affords, when properly applied, the most valuable results. When tin melts at 500°, and pure copper at 2,500°, equal parts of copper and tin do not melt at $\frac{2{,}500 + 500}{2} = 1{,}500^\circ$, but at a lower heat. Platinum, and also chromium, are infusible in our furnaces, but may be made very fusible by the addition of arsenic. Pure iron is extremely refractory, but when combined with arsenic and phosphorus, it may be melted in a cast-iron pot, without adhering to it. Thus, when an alloy of two metals is fusible at a lower heat than the mean of the two, a composition of three metals is still more fusible than their various degrees of melting indicate; and by multiplying the number of component parts a low degree of fusibility of any metal may be obtained. If the composition is according to the laws of chemical affinity, the melting point is lowest. In all cases of practice we must reflect on the application of the metal, before we form an alloy, the object of which is to facilitate the smelting operation. If phosphorus causes iron to be very fusible, and coal, flux, and labor, may be saved in smelting bog ores which contain phosphorus, the first inquiry must be whether the cold-short iron thus obtained is of any value. Arsenic and zinc cause lead and silver ores to be easily melted, but the loss in silver by this operation is so great as to make it desirable to remove these volatile metals before any smelting is entered upon. We may flux copper by arsenic, but not by lead, because we can remove the first in refining, but not the latter sufficiently to form a good quality of copper for sheets. Arsenic, lead or zinc, may be in iron which is destined for wrought-iron, for these metals are easily removed in the refining process. It is always more safe in smelting gold ores to have lead, copper, or silver present, and if possible all of them; for, gold is very volatile and extremely divisible, hence much of it may be lost when no other metals, which act by their quantity, are present. Lead fuses at 600°, tin at 500°, and bismuth at 400°; but a composition of the three may be made which melts at 212°, a heat far below the most fusible of the ingredients. This shows how great the advantages are which may be obtained by forming alloys in the smelting furnaces. It is the degree of fusibility of the slags and that of the metals, which determines the expenses of smelting. The number of alloys is infinite. We cannot establish tables of fusibility *a priori*; these must be determined by practice. In all smelting operations it is necessary to find the most profitable conditions by experiment.

If an alloy is more fusible than a single metal, it follows that, when one or the other constituent is removed, the fusibility of the metal is impaired. An alloy of lead and arsenic is more fusible than pure lead; but when the alloy is exposed to heat for a long time, arsenic will evaporate; and as it was the cause of fluidity, the lead will not be so fusible after losing its flux. Iron is made fusible by the presence of carbon or other substances, but when these are removed, it is very refractory, and can hardly be melted. Upon this principle the formation of wrought-iron is founded; and in applying it to other metals there is no doubt but similar results are obtained. Tin is refined by oxidizing or evaporating sulphur, arsenic, and other matter; this causes the tin to be less fusible, but more tenacious. When zinc is melted in an iron pot, and exposed to the air, it forms dross on its surface like other metals; its fluidity is consequently diminished, but its malleability is improved. A layer of carbon, or, what is still better, a layer of common salt, or bone ashes, prevents such phenomena with zinc and similar metals.

Specific Gravity.—When metals are melted together and form an alloy, there is produced a remarkable change in their specific gravity; which is sometimes greater and at other times less than the mean. A condensation of volume is manifested in melting together zinc and gold; the specific gravity of the compound is greater than the mean of the constituents; gold also and silver condense, or gold with lead or bismuth; silver combined with copper, lead, tin, bismuth, and zinc or antimony shrinks; also copper with tin, zinc or antimony; lead with zinc, bismuth or antimony; mercury with tin or lead, bismuth and antimony. An expansion takes place, when gold is melted with copper, iron, or tin; also platinum with copper; iron with antimony, bismuth, or tin; also copper and lead; tin and zinc, lead or antimony; zinc and antimony, and mercury with bismuth. In consequence of this contraction or expansion we are justified in assuming a similar change in the aggregate form.

The hardness of alloys is generally greater than may be inferred from the nature of the constituents, still there are exceptions to this rule. Silver or arsenic renders iron hard; but these metals are soft by themselves: copper and tin, two very soft metals, may be made extremely hard by melting them together in certain proportions. Hard zinc and copper make soft brass, and a compound of lead and iron is extremely soft. Antimony causes all metals to become hard; iron, with a little antimony, cuts glass very readily, but is very brittle.

The ductility of alloys is in some cases greater than the elements indicate; that of lead and zinc is very tenacious. In most instances the alloy is more brittle than the original metals. Lead and antimony is very brittle. Two or more brittle metals melted together are always brittle. A compound of lead and gold is very brittle. There is no precise limit at which we know when brittle or malleable alloys are formed; it is necessary to find this by practice; but there are strong indications that the alloy of an equivalent composition is always harder than a mere mechanical mixture of metals. Any alloy, when slowly heated and gradually cooled,—annealed—is softer than a compound which is suddenly chilled. In annealing, the various elements which are in combination endeavor to separate. Heat here, as everywhere, weakens affinity. This causes a finely crystallized, or a granulated fracture; the component particles endeavor to assume a round form. When a hot alloy is suddenly chilled, the particles of which it is composed contract suddenly and form a close compact body; at least the ultimate crystals are condensed into the smallest space, which causes them to be hard. This is most strikingly exemplified in some kinds of iron.

Any kind of iron in market may be considered an alloy; there is no such thing as pure iron. Some wrought-iron contains much foreign matter, and still is soft as lead, and fibrous. If such iron is heated to a certain degree, that is, beyond the degree at which it has been manufactured, it becomes cast-iron, is brittle, and when suddenly chilled becomes hard, similar to steel. Such iron may be annealed and softened like steel, or any other alloy. The hardness of an alloy is therefore less dependent upon its composition than upon the arrangement and form of the ultimate particles. We shall refer to this subject again at the end of this chapter.

Oxidation.—Alloys oxidize more rapidly than single metals; to this rule there are, however, remarkable exceptions. Hardened or crystallized metal oxidizes more rapidly, than tempered or annealed metal, which is most strikingly exemplified in iron and steel. It appears that metals expand on being suddenly chilled. The spaces thus formed between the crystals are fissures into which oxygen may penetrate with facility, and as the crystallized form of the particles affords much surface for combination, an oxidation is readily effected. An alloy of antimony and iron, two metals which are remarkable for crystallization, oxidizes very readily; such an alloy may be ignited by mere filing, particularly when it is a little heated previously to that operation. Chrome and lead act in a similar manner. Antimony and potassium burn spontaneously, and if a little warm, with explosion. An alloy of tin and lead—soft solder—burns with a vividness equal to carbon, and if some zinc is present only a low heat is required to ignite the mixture. An amalgam of potassium and mercury is so sensitive to oxygen that the mercury is oxidized to a high degree. In many cases, and under peculiar arrangements, the oxidation is carried to the highest degree: we have seen that in roasting sulphurets, phosphurets, and other compounds, the metal is always oxidized to the highest degree. The same cause acts in both cases. When two or more metals are melted together, there is a perfect penetration of the one by the other. In heating the mass, the tendency to separation is augmented, and as the ultimate particles of one metal cannot congregate and form large particles, they are exposed to the action of oxygen in their minutest form, and consequently will combine with the largest quantity of oxygen. If one kind of metal is more oxidizable than the other, or if the mass is porous, the oxidation goes on, not only faster, but, must proceed to the highest degree, because the atoms of metal may be attacked by oxygen on all sides. While some alloys are easily oxidized, others resist that influence more than pure metals.

Pure iron is very easily oxidized, and often throughout, when in heavy masses. We have stated in another work, that a lot of bloom four inches thick, of puddled iron, was oxidized in a reheating furnace by giving merely a drawing heat to such a degree, that when drawn out between rollers into bars, these were found to be converted partly into magnetic, and partly into protoxide of iron. This iron was puddled under the influence of a cinder highly charged with chlorides. Metals are porous, and easily penetrated by other matter. Thus, water enters successfully into the body of cast or wrought-iron; and if a metal is present, or any other substance which decomposes water, the iron is easily oxidized. We find, when carbon is present, that oxygen has little effect on iron; but when any of those substances which form acids, such as arsenic, antimony, or sulphur, are combined with the metal, it is an easy prey to oxygen. An alloy of chromium and iron resists oxygen as well as gold; and phosphuret of copper is not so easily affected as pure copper. Bronze will resist the influence of oxygen much longer than pure copper.

This subject of oxidation is of much practical interest, and deserves more attention than has been paid to it by metallurgists. It seems that no definite rules can be applied; so far as we know, nothing is settled respecting it. It appears, that the degree of affinity has less influence on the oxidation of metals than the aggregate form of their particles, and the strength of their union. Hardened steel oxidizes more readily than annealed steel, and chilled cast-iron more so than gray cast-iron. Hammered or rolled lead is less penetrable by mercury than cast lead. German silver, which is composed of oxidizable metals, is little affected by oxygen, and less so when rolled than when cast. Copper has a strong affinity for sulphur, and is more readily attacked by it than iron, when finely divided; yet, when in a compact body, it will resist that substance far more successfully than iron. Some kinds of brass are remarkably liable to oxidation, while others resist it more effectually. A surface of metal which is highly polished, and particularly when polished by rubbing it with a hard substance, is far less subject to oxidation than a rough surface. If it is desirable to resist oxidation, or in fact the influence of any other matter upon metal, those alloys must be formed which have naturally little affinity for that particular substance, and which, in the mean time, form the most intimate union, so that the penetration of foreign matter into the body of the metal is prevented. It is not the compactness of zinc or lead which prevents their oxidation in the atmosphere; it is the cover of oxide, which forms a close body, and prevents the further penetration of oxygen. We may assert that the density of gold and silver has as much influence in preventing their oxidation, as their want of affinity for oxygen. Affinity between the metals of an alloy has, in consequence of an intimate union, a large share in preventing oxidation. Iron is easily oxidized, but it is less subject to that influence when combined with phosphorus than when alloyed with silver or gold, particularly the former; this is chiefly because silver has but little affinity for it, and is thus excluded from its crystals, and forms a layer between them. There is a separation; oxygen finds access, and a rapid action of it is the consequence. Carbon protects iron successfully, not in consequence of its greater or less affinity for oxygen or iron, but chiefly on account of its form. Carbon is elastic, and will fill the spaces between the particles of metal. When gray or white cast-iron contains five or six per cent. of carbon, the latter will form a body, when liberated, which cannot be condensed into the same space again by any mechanical means; and even in the form of graphite, it occupies nearly the space of the iron. Still, cast-iron is porous. All substances foreign to iron, which are contained in the finest kind of cast-steel, cannot, when liberated, be condensed into the same space which they occupied in the steel; and such steel, when glass-hard, is very porous; there is not even cohesion between its particles; it is brittle. In this may lie the apparent secret of hardness.

Every alloy, as far as regards utility, may be considered a new species of metal, because the qualities of the constituents are, in most cases, not recognized again in the compound; it shows properties which do not belong to the simple metals, and which cannot be determined by theoretical speculations. By changing the proportions of tin to copper, we obtain bronze of different qualities, varying extremely in color, hardness and sound. All the alloys of tin and copper are harder than either element, and half and half is as hard as steel, but extremely brittle. A few per cent. of tin causes copper to be hard, and more tenacious. The addition of a little lead causes brass to be more ductile, while a large addition makes it brittle. Silver is rendered hard by the addition of a little copper, while copper is more tenacious in combination with a little silver. It would lead us too far now to exhaust this subject. We shall again allude to the alloys.

CHAPTER II.

Potassium.—We commence the subject of smelting with a series of metals which have no practical value by themselves, but which are of great interest when combined with others. As pure metals are not formed in the smelting operations, all matter which possibly may enter into combination with the metals, is of interest to the smelter. For these reasons, we allude here to some of these metals, so far as they have any influence on others.

Potash.—The oxide of potassium, its ore, occurs in the ashes of all land plants and of the animals; it is found in all rocks in large or small quantities, particularly in clay, in feldspar and in granite, in mineral coal, in iron ore and some other ores, also in some mineral waters. The best source of potash is the ashes of plants, some kinds of marl (New Jersey marl contains ten per cent.), and feldspar; from which potash, the hydrated oxide of potassium, is extracted. This, however, is combined with carbonic acid when brought to the solid form, in which we generally meet with it in commerce. Potassium is manufactured from pearlash—carbonate of potash—by dissolving it in water, and mixing it with half its weight of coarsely pulverized charcoal, then evaporating it to dryness, and exposing the black mass thus obtained in a wrought-iron vessel to ignition. At a white heat the potassium evaporates, and is conducted through iron pipes into a receiver filled with naphtha. Another method is to char a mixture of cream of tartar—bitartrate of potassa—and charcoal-powder, in the same manner as black flux, and expose this mixture to ignition in an iron flask, as above. When coarse iron filings are heated to redness in a wrought-iron bent pipe, or in a flask, and previously heated caustic potassa is dropped upon it, the latter is decomposed by the hot iron the oxygen absorbed by it, and potassium is liberated, which is condensed as above in a copper receiver filled with naphtha. Black flux, mixed with oil, or fine carbon, and ignited in a retort, furnishes also an abundance of potassium. In fact, any substance which contains much potassa, and is heated together with carbon, with the atmospheric air excluded, furnishes the metal.

Potassium is the first in the series of electro-positive metals, and has consequently a great affinity for all other metals; we may, therefore, expect to find it alloyed where metals have been smelted by charcoal, or from ores which contained potassa. But, as potassium is extremely volatile, it evaporates from those metals which require a high heat for smelting, and to which it has not a great affinity. It combines most readily with antimony and arsenic. In combination with the first, we obtain it in large quantities by melting antimoniate of potassa, together with coarse charcoal-powder, in an iron crucible, under cover of borax and black flux. Lead, in being reduced from litharge, and when fluxed with black flux, absorbs a large quantity of potassium. When antimony is present, this quantity is considerably augmented; in fact, potassium combines more readily with an alloy of lead and antimony than with either of these metals when alone.

Potassium has a remarkable tendency to soften other metals; and, without any pretension to establishing a rule, we are led to believe that electro-positive metals have a softening influence upon others. It is an established fact, that all metals smelted by charcoal are softer and purer, and more compact, than those smelted by other fuel. In this case, as in all others, a small portion of that substance with which a metal was revived, will remain in it. We are therefore justified in assuming potassium to be present in pig iron smelted by charcoal. Its presence in other metals than iron cannot be doubted, if they have been revived by means of charcoal. It may be objected, that no potassium has been detected in any of the assays of iron, but this cannot affect the assertion, because the small quantity which may be present, and is sufficient to produce the effect, easily escapes the observation of the assayer. We do not wish to be understood as insisting upon the presence of potassium in charcoal pig-iron; but if it is present in but small quantities, the superiority of charcoal pig for forgers is easily explained; and its general brittleness in castings is accounted for. When all electro-positive metals have a tendency to soften other metals, it does not follow that potassium is present to produce that effect.

Sodium.—The sources whence this metal is obtained, are its oxides and salts; of the latter, carbonate of soda is the best for producing the metal, and chloride of sodium the most extensively distributed. The carbonate occurs in sea-weeds, in some land plants, in some lakes of Egypt and Europe, and in stone-coal. Sodium is most abundant in sea-water and salt-springs; it is not so much distributed in the form of carbonate of soda, as in the carbonate of potash. Sodium is prepared by the same means as potassium, from similar salts; but as it is more refractory than the latter metal, it will bear a stronger heat; and, for this reason, it will alloy more readily with other metals. It is a little heavier than potassium, its sp. gr. is ·97, and not quite so soft as the latter metal at, or near, the same degree of heat.

Sodium alloyed with potassium is more fusible, and more permanent; that is, it will bear a higher heat than either metal alone; the alloy is brittle, but not hard. One part of potassium, and three parts of sodium, or more of the latter, is fluid at the freezing point of water, while the first metal melts at 136°, the latter at 194°, the mean of which is $\frac{194 \times 3 + 136}{4} = 179°$. This shows a remarkable gain in fusibility. All the alloys of sodium with other metals appear to be stronger than those of potassium, and they are harder.

Barium.—This metal is derived from barytas. The carbonate of baryta is formed into a paste with water, and thus may be decomposed by electricity, a method by which, in chemical laboratories, many other metals are produced. It may also be smelted from the oxide of barium; this, however, is attended with some difficulties. It is produced readily by alloying it, in smelting, with another metal; in which case, it combines with most of the metals. It is far heavier than potassium or sodium; its specific gravity is near 3. It oxidizes rapidly in the air and in water, and fuses below a red heat. It is also malleable.

Calcium.—This is similar in all its properties to barium, and is produced in a similar manner. It oxidizes as easily as the foregoing metals, and is in fact little distinguished from them.

But little is known of the metals of the alkalies, and the alkaline earths; they all decompose water with more or less energy, from potassium, which burns vividly on ice or water, to magnesium, which is not altered either by air or water at a low heat; although it burns when heated to redness. These metals are all volatile at a red heat. They melt from the point of freezing water to a red-heat, at which magnesium melts. Calcium and magnesium have been detected in gray pig-iron, and we may expect that these metals are alloyed with others where the smelting is performed by hot blast and an excess of alkaline flux. All the alkaline metals decompose silex, and to find them alloyed, it is necessary that silicon should be reduced first. Silex is reduced under the same conditions with the alkaline metals, and sooner than they are. As silex is always present in smelting operations, its reduction cannot be prevented when these metals have been revived. And as the affinity between them and silicon must be naturally very strong, the latter must exist in all cases where the first are found. This may be the cause why we know so little of the alloys of the metals proper, and the alkaline metals; for, where these are, silicon must be, and it imparts its own character to the metal. We may, however, recognize any metal which has calcium or magnesium in its composition, by its tendency to oxidize. When calcium is, to some extent, in pig-iron its fracture is close; little tendency to crystallize is shown; it is very fluid, extremely brittle, and causes much work and loss in refining. This may not be in consequence of the calcium present, but the amount of silver which is in proportion to the calcium. Should it ever be an object to produce the alkaline metals on a large scale, it will be done by alloying them with lead or copper in smelting, and liquidation.

Aluminum.—This metal does not properly belong to the foregoing series, still it forms a link between it and the metals proper; and as its electrical indifference is most striking, and its effect upon other metals has been more investigated than the foregoing, it affords the means of drawing comparisons. Aluminum is produced from alumina by a peculiar smelting process, which in some measure belongs to our department. When pure alumina—the oxide of this metal—is mixed with finely pulverized carbon, and exposed in a porcelain tube to a red heat, and, in the mean time, chlorine is conducted over it; a dry chloride of aluminum is formed, accompanied by a vivid combustion. When this substance is placed in a porcelain crucible, upon whose bottom some pieces of pure potassium are deposited, and the crucible is well covered and luted, and then gently heated over a spirit lamp, a reduction of the alumina is performed by the potassium, with the production of a high heat at the moment when these two metals decompose each the other. Here is a reduction of one metal by the other, as we have seen it performed in reducing sulphurets. This operation is, therefore, not confined to sulphur, oxygen, phosphorus, and similar substances; it applies to all metals and their combinations, and it requires nothing but a proper selection of the decomposing substance, and the conditions under which it may be performed.

The aluminum thus obtained, is similar to the alkaline metals; it is very refractory and does not melt at the heat of melted cast-iron; it is hard, tenacious, and not oxidized at common temperatures, but requires a high red-heat for oxidation. This metal has been observed alloyed with iron, in Indian steel, and it has been said that the excellent qualities of that steel are owing to its presence. Experiments which have been made with this view have shown, that iron combined with aluminum is remarkably strong. In endeavoring to combine aluminum with another metal we are in the same predicament as with the alkaline metals; silex is reduced before alumina is affected by carbon, and if any advantages are to be derived from an alloy of this kind, silex ought not to be present at its formation.

All theory and experience indicate the softening and strengthening influence of the alkaline metals, from aluminum to potassium; but in the large operation, and the reduction of the oxides, we are certain to reduce silex with them, which not only paralyzes their good effects, but makes them so injurious that their presence is a decided disadvantage to the ductility and strength of the metals with which they are combined. This is reecognized in lead and iron. If metals can be reduced in the presence of alkaline substances from sulphurets, phosphates, or chlorides, there is a possibility of obtaining alloys free from silicon.

CHAPTER III.

Selenium.—This metal is closely related to sulphur. It occurs in native sulphur, in galena, in copper and iron pyrites, and it has been observed in the tellurates of Virginia. Its preparation is a chemical process which does not come within the scope of this work. But, as it is the first substance in a series of metals of a decided electro-negative character, and has metallic properties, such as malleability and lustre, we must recognize it as a useful metal. It fuses at the boiling heat of water, and boils at a red heat and evaporates. It is so nearly allied to sulphur, that all which may be said of the latter, is applicable to it. It adheres more tenaciously to metals than sulphur, and enters into combinations where sulphur does not, such as with aluminum. In fact this substance, as commonly understood, is a little more metallic in its nature than sulphur.

Tellurium.—This metal seldom occurs. We should not allude to it, if it did not bear the character of a metal. In Virginia and North Carolina, it is found in combination with silver, and gold, and bismuth. The mode by which it is obtained from its ore differs from our method of producing metals, and since it is of little interest we shall omit a description of it. In appearance it is similar to silver, and like antimony inclined to crystallize. Its specific gravity,is 6·115, and it is very refractory requiring a white heat for evaporation. It is more volatile in an atmosphere of hydrogen than in common air, and its fusibility is similar to that of antimony; it is combustible when red hot, and burns with a blue flame, free from all smell when the metal is pure. When cold it resists the action of the atmosphere very well. The alloys of tellurium with other metals are extremely brittle, and similar to those of sulphur and selenium. The union of potassium and tellurium is very brittle, and when in certain proportions, is soluble in water, without oxidation, like the compounds of oxygen, sulphur, selenium, chlorine, and others. Tellurium and aluminum, combine with the liberation of a strong heat; both unite when in the form of a powder with the force of gunpowder. This alloy is easily oxidized by water or moist air, forming alumina and tellurium. Little is known of the tellurets generally. It is said, and may be adopted as true, that all tellurets except those of gold, silver, and a few others, are easily decomposed. We must take this assertion with the usual proviso, that, when the amount of tellurium in another metal is very small, the atmosphere or moisture will have little effect on it.

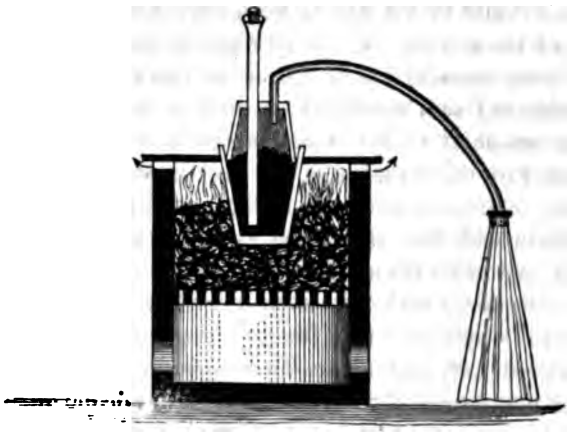
Arsenic.—This is a metal which is more plentifully supplied by nature than those above mentioned; and as it is similar in character to them, its effects on other metals are also similar. Arsenic is chiefly obtained from arsenious acid, and the latter by calcination from native arseniurets, such as those of iron, copper, and other metals; hence it is, in most cases, a secondary product. Still, much of the arsenious acid of commerce is manufactured from iron pyrites, which, when the arsenic is extracted, serves no other purpose. Arsenic enters as an important agent into many branches of art, and is a useful metal in forming fusible alloys. Arsenic metal is not poisonous, but one of its oxides—arsenious acid—formed by its combustion in air, is extremely so; and in operating either with the metal or the acid some caution is required on the part of the operator. When arsenious acid is operated on, if we moisten it, the inhalation of the dust is prevented. And when an alloy of arsenic is melted, and operated on, the vapors of this metal are made harmless when the operator fills his mouth with grains of charcoal, renewing them from time to time. This charcoal will absorb any arsenic which may accidentally enter the organs of respiration.

Arsenical pyrites is the common ore of this metal; it is here combined with iron, silver, gold, bismuth, and antimony. Not much arsenic has been discovered in the United States. New Hampshire, the Southern gold regions, and Pennsylvania, have furnished the only specimens of arseniurets, but not in sufficient quantity to be useful in the arts. Europe furnishes to our country at present all the arsenic, in the form of arsenious acid, but we do not doubt that it will be found at some future time in the regions of the sulphurets. In all cases of its application in practice, we may consider the arsenious acid as the only ore; and as this is obtained as a secondary product in the calcination of cobalt ores, we shall include the description of its manufacture in the chapter on that substance. If arseniurets of iron were found sufficiently abundant in this country, to admit of the manufacture of arsenious acid, the price of the European article is so low as to render its manufacture unprofitable here.

The arsenious acid of commerce is white, glassy when fresh, but generally opaque when brought into market for sale. For metallurgical purposes no arsenious acid in powder ought to be used, for it is frequently adulterated with gypsum or other matter. The commercial article is always more or less perfectly glassy or milky, or transparent in the interior of the flat pieces, while on the exterior it appears opaque; it is generally vitreous throughout its whole mass. It is slightly soluble in water. About ten parts may be dissolved in boiling water; this quantity, however, depends on the amount of acid present. Water never dissolves the whole of it, even when less than the above quantity is exposed to its action; it will dissolve more when a large quantity of acid is afforded. Arsenious acid consists of 75·8 metal, and 24·19 oxygen. It sublimes in open vessels at 380°; it is decomposed by hydrogen, carbon, sulphur, phosphorus, and some metals, such as lead, iron, silver, &c.

The metal arsenic is easily obtained pure when arsenious acid is mixed with fatty oil, or a compound of carbon and hydrogen, or finely-pulverized soft charcoal, and heated gently in a glass tube. It evaporates at 356°, and is therefore easily smelted, and the metal condenses in the cold parts of the heated tube. In large quantities it may be obtained by mixing arsenious acid with coarse charcoal powder, or what is better still, culm—small fragments of bituminous coal—and exposing it in a large crucible to a red heat. This crucible is covered by a second one, as shown in fig. 204, and well luted; the lower pot is exposed to a red heat, while the upper one is kept cool. The metal thus formed and evaporated will condense in the upper pot, from which it is easily separated, when cold. The same operation may be performed on arsenical pyrites, without carbon, and the metal is obtained in a similar manner. Iron, nickel, and other permanent metals remain in the lower pot, combined with some arsenic.

FIG. 204.



The metal is of a high lustre, and grayish-white; its specific gravity is 5·70. Its weight and lustre increase with its purity. It evaporates without melting, and its vapors, which smell strongly of garlic, are sometimes confounded with those of phosphorus. Arsenious acid does not smell, it is the metal only which emits this odor. It is not ductile, nor malleable, and may be converted into fine powder in a mortar. It is highly combustible, and deflagrates when either mixed or heated gently with saltpetre.

If this metal, in its pure state, is of little interest to the metallurgist, its alloys are of much value. All metals, without an exception, are made more fusible by the addition of arsenic; in some instances its influence is remarkably distinct. The alkaline metals combine with it with great facility, even when it is simply heated with the oxides of those metals—such as potassa or soda. It requires extreme caution to operate on these alloys; that is, on those of the alkaline metals and arsenic, because they decompose rapidly in damp air, and evolve arseniuretted hydrogen—a virulent poison—the effect of which resists the most refined skill of the physician. In combination with lead—in shot

—arsenic is harmless; and also in all compounds of the proper metals, when its quantity is not too large. Aluminum, and all the metals of this class, combine very readily with arsenic. In fact all metals combine easily with arsenic, but they are quite as easily decomposed. The decomposition of arsenical alloys is effected by merely continued heat, and with the exception of silver, in a short time. The higher the degree of heat is, so much shorter is the time in which the act is accomplished. When it is desirable to retain arsenic in the composition, it is necessary to melt the metals at as low a heat as possible. The combination of arsenic with other metals is as easily performed as the decomposition. Metallic arsenic and lead cannot be combined directly; but when melted lead is covered by arsenious acid, some lead is oxidized, and in its place arsenic is absorbed. In the same manner other metals, which melt at or near the heat at which arsenious acid volatilizes, may be combined with arsenic. Iron, chromium, copper, and others, cannot be alloyed by these means, but they may be effectually combined with arsenic in a manner described in previous pages; and there is no doubt that all alloys of this kind are most safely and correctly compounded by that manner—namely, cementing the metals directly, or their oxides, with arsenious acid and carbon, at a heat at which neither the refractory metals nor the alloy is melted, and then melt the alloy thus formed at the lowest heat at which it will dissolve in a crucible, with the exclusion of oxygen; that is, under a cover of fusible glass.

Alloys of arsenic cannot be converted into vessels in which food for men or animals is prepared, but it finds extensive applications in other cases; and when its properties are more thoroughly understood, it will be still more generally used. In virtue of its property of causing the fluidity of metals, when present in small quantities, it promotes the union of those metals which, without its assistance, do not unite. Zinc and lead do not unite very readily; but with the assistance of a little arsenic, both form a firm combination. Iron has no affinity for lead, but when arsenic is present it forms an alloy with it. Thus we may form combinations which, without the assistance of arsenic, cannot so easily be accomplished. Iron and alumina may be formed by melting gray-iron and pure alumina together; in this case all the impurities of the cast-iron are in the compound. When pure iron filings or turnings, are cemented in alumina, arsenious acid and carbon, and then melted in a crucible so as to expel the arsenic, an alloy of iron and aluminum of great purity is formed, which, however, contains traces of arsenic. Arsenic, like antimony, has a remarkable tendency to cause metals to crystallize; but it does not make quite as brittle alloys as the latter. In producing a high degree of fluidity, it admits the melting of metals at a low heat, and consequently the formation of small crystals and a fine grain, and enables the metals to contract into a small compass, which causes them to be close and assume a high polish. With the closeness of grain, the hardness and brittleness increases. Arsenic causes all metals to be whiter then they naturally are.

Chromium.—This metal has been but very little used in its proper form. Its compounds with oxygen are introduced as coloring matter very extensively. The metal possesses some properties which deserve more than a passing notice.

Its ore is the chromic iron—chrome ore; also called chromate of iron. It occurs native in heavy masses, of a granular texture, of an iron-black or brownish-black color; streak brown; its fracture is uneven, and it is brittle. Chromic iron occurs chiefly in Maryland and Pennsylvania, and to some extent in Europe; but the first sources scarcely supply the markets of the world. The most extensive mine may be considered to be that in Chester county, Pennsylvania, which furnishes a large quantity, besides an ore of remarkable purity, containing often from 90 to 93 per cent. of chromate in the bulk. This mine has been worked now for fifteen years, and the mineral appears to be inexhaustible. It contains, besides chrome ore, magnesian minerals; and yields also specimens of nickel ore, and emerald. Chromate is found near Baltimore on the bare hills, and in Montgomery county, Md., and other counties of that State; in Connecticut, in New Jersey, and in Vermont in large masses; in Massachusetts, in Cuba, and other localities. This ore is generally imbedded in serpentine, in the form of masses or veins.

The composition of chromic iron is oxide of chromium, protoxide of iron, alumina, silica, and other substances. A specimen from Chester county, Pa., contained 51·56 chrome oxide; 35·14 peroxide of iron; 9·72 alumina; 2·90 silica. Another specimen from the same source, 60·04 chrome oxide; 20·13 peroxide of iron; 11·85 alumina, and some magnesia. Frequently the ore contains manganese besides these ingredients. When it is gently heated with carbon, or in the reducing flame of the blowpipe, it is rendered magnetic. It dissolves, with a green color, when melted with the bisulphate of potassa.

There are other ores of chromium than these; but they are of no practical interest. The metal chromium is extremely refractory, and in its pure condition of no use. It may be produced in small grains, or in an imperfect form, by heating green oxide of chromium in a charcoal-lined crucible, in the strongest heat of an air, or blast furnace. The metal is grayish-white, specific gravity 5·9, very brittle, not magnetic, and not attacked by any acid except fluoric, which dissolves it. It changes slowly in air or water, and decomposes the latter at a red heat; when heated with potassa or soda, or their carbonates, it is converted into chromic acid. An easy mode of obtaining this metal, is to dissolve sugar in a solution of bichromate of potash—dry the whole, and burn it by stirring it with a hot iron rod. When this mass is exposed in a good black crucible to a strong heat, a scale of chromium is formed near the sides of the pot, which may be separated from it, and from the inclosed oxide. The metal thus obtained is soft; it cannot be pure; and it must contain potassium.

Chromium has a strong affinity for sulphur, phosphorus, and some of the metals. Like arsenic, it has a tendency to harden other metals. Its refractory nature, admitting of a high degree of heat before melting, combined with its property of hardening—which it possesses in a high degree—and its abundance, render it the most suitable and best metal for compounding hard alloys. Its resistance to oxidation, either by itself, or in combination with other metals, makes it useful for those purposes for which other metals, except gold or platinum, cannot be applied. Iron is made extremely hard in combination with it, and it retains its tenacity when pure.

To produce chromium by smelting it directly from its oxides, is an operation too expensive for practical purposes; but we may obtain it alloyed to others, with the greatest ease, when bichromate of potassium is dissolved in water, and a little arsenious acid added to it, and also pure peroxide of iron and an equivalent of charcoal-powder which may absorb the oxygen from the oxides; if the mass is then evaporated to dryness, we obtain an intimate mixture of the metallic oxides and carbon. This dried mass is broken into coarse pieces, so as to form spaces, and melted in a Hessian pot, under cover of a little piece of window-glass which is free from lead. By applying a gentle heat, an alloy is thus obtained of great fusibility, extreme hardness, and which is not brittle. If the arsenic in this alloy is in any way objectionable, it may be re-melted by a gentle heat, under cover of glass, until all, or nearly all of it is evaporated. An alloy of copper and chromium is formed in a similar manner; but it requires more caution in evaporating the arsenic, so as not to oxidize the chromium. In these experiments any excess of carbon must be prevented, because it renders the compound brittle; it is therefore of little use to alloy chromium with steel. All the metals belonging to this class of extreme electro-negatives, do not readily combine with carbon, boron, or silicon; and if these substances are present in the principal metal, the addition of another metal which has no affinity for them, will render the first brittle.

In forming an alloy of chromium with other metals, the potash of the bichromate is sometimes objectionable, because some of it may be reduced and enter into the alloy, which is the more probable, as chromium has a strong affinity for potassium; in such case, the chromate may be converted into oxide of chromium by simply calcining it with charcoal, and extracting the potash from the calcined mass by water. The result is more certain, and a purer oxide of chromium is obtained, when the bichromate of potassa is dissolved, mixed with an equal weight of carbonate of potash and 1½ times its weight of sal-ammonia, and evaporated to dryness and calcined in a crucible by applying a red heat. The chloride of potash is extracted by water from this mixture, and a green oxide of chromium remains.

Titanium.—This metal would be of little interest if its oxide, or acid, was not found so frequently associated with the iron ores of this country, in smelting which it causes so much difficulty. The most frequent occurrence of titanium is in the titanic iron, which abounds particularly in the eastern and northern States. The black magnetic iron ore, and iron sand, contain titanium. The metal is frequently observed in iron smelting furnaces, as an accidental deposit. In this case, it is generally combined with nitrogen and cyanogen, and represents $10 \text{ Ti.} + 1 \text{ Cy.} + 3 \text{ N.}$ It is also found in the iron slags, but most frequently in the crevices of the old hearthstones of these furnaces. When obtained in combination with iron, in such stone fractures, it is converted into a copper-red powder by dissolving the iron in muriatic acid. Titanium may be produced like chromium, by exposing a mixture of titanic acid and carbon to the strongest heat of an air-furnace provided with blast. It does not melt, but is reduced to a red porous mass. This metal is extremely hard; it cuts glass, hardened steel, and agate, and is insoluble in all the acids, except nitro-fluohydric acid. It is not altered in air or water, and can be oxidized only by melting its fine powder in saltpetre. Titanium is, like chromium, not easily combined with other metals; this is chiefly owing to its refractory character. It has only a weak affinity for sulphur, phosphorus, carbon, and similar matter. Alloys of titanium are little known, but they deserve more attention than has been bestowed upon them. Those which have been examined are all extremely hard, and less brittle than the alloys of other electro-negative metals.

We have thus far treated of a series of metals which are of little practical value by themselves, but of high interest when alloyed with others. And, as we cannot smelt any one of the common metals without its absorbing some of the matter with which it is in contact, we may assert, as a general rule, that all commercial metals are alloys. The foregoing series of metals show distinctly the character which they impart to an alloy, and we are justified in assuming that electro-positive metals, that is, those which form the alkali in an alloy, have a softening influence; and those which form the acid, cause hardness. Brittleness is determined by the relative degree of fusibility of the alloys. All the compounds of the alkaline metals are not so brittle as those of the acids. Still, an alloy of aluminum is stronger than that of potassium or calcium; and an alloy of chromium or titanium far stronger than a combination of arsenic or selenium; this may be owing to the refractory character of the latter.

In the preceding remarks, we have purposely omitted to speak of carbon, sulphur, phosphorus, silicon, and some rare metals; these substances may, and must be, classed with the metals; we shall speak of them hereafter. The combinations of sulphur, phosphorus, &c., are similar to those of other alloys; and in carbon we recognize the strong character of an extremely refractory metal, more determined in its nature than other metals. We recognize in the diamond a metal condensed in the smallest space. Carbon requires, besides heat, a strong pressure to agglutinate, which is shown distinctly in its combination with iron. When, under these circumstances, that metal is heated to a certain degree, the carbon is dissolved in the iron; and if the latter is suddenly cooled and forced to crystallize, there is no time for the carbon to separate, and an alloy is the consequence, which shows all the characters of other alloys to a high degree. We are justified in assuming that carbon is, in hardened steel, in the form of diamond. The limited affinity of metals for carbon, and the refractory nature of the latter, cause it, when it is subjected to a strong compressive force, to separate from the metal and occupy the spaces between its atoms, which renders the metal gray and soft. We shall allude to this subject again in subsequent pages; our object here is merely to draw attention to the metallic nature of all that matter which combines with metals, and forms alloys.

CHAPTER IV.

Zinc.—The properties of this metal, when pure, are characteristic. The commercial zinc is not pure, it always contains foreign matter, such as carbon, arsenic, lead, cadmium, iron, and in fact all those substances with which the ore has been in contact, and with which it is brought in contact in the process of distillation or smelting. Pure zinc is a bluish-white metal, much inclined to crystallize, and consequently brittle and of brilliant lustre. It fuses at 770°, and evaporates at a heat near the melting of cast-iron. Between a temperature of 200° and 300° it is quite malleable, and may be rolled into sheets, hammered, or drawn into wire; below 200°, and at 400°, it is quite brittle. At these temperatures, it may be converted into powder in a mortar. The specific gravity of the pure metal is 6·9, that of the article of commerce, 6·6 to 6·8, that of the common rolled metal, 7·19. Zinc decomposes water when in the form of vapor; it tarnishes in moist air, but continues bright in dry air; when melted, with a supply of air it burns with a vivid white flame, giving out dense fumes, which condense in white flakes, like fine snow or wool; this is oxide of zinc. By the form of these, it is distinguished from all other metals; for no others form such large flakes of oxide—flowers of zinc—as this one in burning. Zinc has little affinity for other metals. When thrown on melted iron, it is evaporated with such rapidity that the fluid iron is thrown about; and when the piece of zinc is large, and cast into the melted iron with force, an explosion similar to that produced by gunpowder is the consequence. Copper, to which zinc has the greatest affinity, cannot retain it when melted. Pure water is not decomposed by zinc at common temperatures, but it decomposes steam, when ignited; the metal is rapidly dissolved by water, which contains an acid or an alkali in solution.

Oxide of Zinc.—The principal ores of zinc are the sulphurets, silicates, and carbonates. Oxide of zinc only is used at present in the United States for producing zinc. Pure oxide of zinc—flowers of zinc—consists of 81 parts of the metal, and 19 parts of oxygen, which in the native oxide is more or less mixed with other matter. The red oxide of zinc of New Jersey is the mineral used at present; it is a compound of zinc, iron, and manganese. It occurs abundantly at Stirling and Franklin, N. J. It is of a dull orange, often deep red, or brown-red color; it is brittle, infusible, and contains on an average from 80 to 90 per cent. of oxide of zinc; sp. gr. 5·4 to 5·5. This ore is used at present for the manufacture of white zinc paint, at Newark, N. J., and to a small extent in the manufacture of brass.

Blende.—Sulphuret of zinc, black-jack. This ore consists in its pure crystals of 34 parts of zinc, and 16 of sulphur. It is always found to be crystallized, of a high, adamantine lustre; of black, brown, red, yellow, and green colors, and in most cases transparent, or translucent; it is brittle, and its specific gravity 4 to 4·2. Its conchoidal fracture, together with its small gravity, causes it to float easily in water. Blende occurs in crystalline and in stratified rock, associated with galena, heavy spar, copper and iron pyrites, fluor spar, spathic iron, and other minerals. This mineral abounds in the western lead mines, in Missouri, Wisconsin, Iowa, and Illinois. It is found in the States of New-York, Massachusetts, New Hampshire, Maine, and in fact in nearly all the States of the Union. Blende is the principal substance in the silver ores of Virginia and North Carolina, where it occurs in heavy lodes, injections in talcose slate. It is not used for the manufacture of zinc, and is considered a troublesome mineral when intimately mixed with galena, for it causes the latter to waste much in smelting. When galena, which contains blende is crushed, but not too finely, the latter may be removed, to a large extent, by washing. When crushed fine, the galena and blende are inseparable. It is a most tedious operation to separate sulphur from zinc, particularly when in combination with other metals which form a fusible sulphuret.

Calamine.—In this species the carbonate and the silicate of zinc are contained; both are treated in the same manner for obtaining the metal. The specific gravity of the first is 4·2 to 4·3, of the latter 3·8 to 4·1. Composition 64·8 oxide of zinc, and 35·19 carbonic acid; it contains often carb. of iron. This species occurs extensively in Missouri, in New Jersey, Perkiomen mine in Pennsylvania, and also in Connecticut. Its color is white, brownish-white, greenish, and similar shades; it is translucent, of a vitreous or pearly lustre, streaked white, and brittle. Silicious oxide of zinc occurs with the carbonate in the same localities, and does not materially differ in appearance from the latter. Its composition, for which a specimen from Stirling, N. J. is adopted, is 68·06 oxide of zinc, 25·44 silica, and the rest 6·50 iron and manganese.

Alloys of Zinc.—Zinc has a faint affinity for carbon; the commercial article always contains it; it has a strong affinity for arsenic, and can hardly be freed from it by any means. Potassium and sodium combine readily with zinc; and its effect in this combination is similar to that of antimony, lead, or bismuth. Sulphur and selenium do not readily combine with zinc, but tellurium does, with the development of intense heat. With antimony it combines, but not very readily. All these combinations are more or less brittle, and not ductile. The alloys of zinc and other metals are more or less malleable, according to the proportions of zinc. Lead has a peculiar influence in diminishing the brittleness of zinc; even two parts of zinc and one of lead are not brittle. Tin and zinc is hard, but forms a very compact metal. Bismuth and zinc do not combine; but when a little antimony or arsenic is present, a union may be effected; the compound is similar to that of lead. The precious metals do not easily combine with zinc. Iron is the only metal with which it combines, when the mass of either is very large; a little iron combines easily with zinc; the commercial article always contains it. Iron may be superficially coated with zinc, but at a red heat it entirely evaporates. Zinc containing iron is more subject to oxidation than pure zinc; iron appears to predispose it for oxidation. Of its compositions with copper, and also of other metals, we shall speak again.

Use of Zinc.—Its use is chiefly for alloys with copper, and for scientific purposes. Its excessive sensitiveness for acids and alkalies excludes it from domestic utensils. In sheets, it is sometimes used for covering roofs, or for covering wooden floors in houses which are much frequented. When rolled at the proper temperature, about 300°, and gently cooled, the sheets retain their malleability; but if this apparent malleable metal is melted and cooled, it assumes its brittle nature again. When the sheets are warmed, they are less subject to fracture than when cold. Zinc is used to protect iron against oxidation, which it does effectually when both metals touch each other, or are in metallic contact. The iron for this purpose is cleaned on its surface by a mixture of equal parts of sulphuric and muriatic acids, which is diluted and warm; it is immersed in this fluid, and when clean, or nearly so, it is struck by a hammer to remove the adhering scales, scrubbed with sand or emory, and then dipped in a bath of a saturated solution of equal parts of chloride of zinc and sal-ammonia. From this theiron is transferred to a metallic bath, of melted zinc and mercury, 1292 parts of the first to 202 parts of the latter. To one ton weight of this mixture, one pound of sodium is added. The iron is suffered to remain in this hot bath until it assumes the temperature of the melted metals, when it is found to be coated with zinc. The feeble affinity of these two metals is so much increased by this peculiar treatment, that thin sheets of iron, or iron wire, are soon entirely dissolved in the metal bath. In order to prevent the rapid solution of iron, the zinc is partially saturated with that metal before the plates are immersed. A sheet of iron, $\frac{1}{8}$ of an inch thick, may be dissolved in a few seconds when hot. Zinc combines readily with bronze, and forms a hard, close metal, which is extremely useful for pans to run shafts in, or for similar purposes. Zinc is used for door-plates and knobs, after being covered by a galvanic process with a strong plating of silver.

Manufacture of Zinc.—No zinc is, as yet, smelted in this country; the low price of the European article renders it unnecessary to use our rich deposits of this ore. For these reasons, we are compelled to describe the European operation, and shall do so with reference to the labor required to obtain the metal. All zinc ores, except the red oxide, must be roasted before they are fit for reduction. This is done in large reverberatory furnaces, similar to those in which copper, tin, or lead ores are roasted or smelted. The hearth of such a furnace is about 10 feet long, and 8 feet wide; and the ore, coarsely bruised, is spread in a uniform layer about 6 inches thick over the hearth. The heat is to be moderate, or the volatile zinc evaporates. From four to five hours' roasting, with constant stirring, are required, to evaporate water and carbonic acid, after which the roasted ore is removed from the furnace to be mixed with culm, small coke, or small charcoal, as the case may be. About 30 to 36 per cent. in weight is lost in this operation, and the bulk is diminished in ratio. In order to save this labor, the ore is not roasted in some parts of England, but well picked by hand, broken into pieces of the size of a hickory nut, and mixed with an equal volume of small stone-coal. Not much is gained by omitting to roast the ore; it is in this case more bulky, the retorts take less of it, and do not last so long as when used for roasted ore.

In some parts of Europe, England and Switzerland, blende is roasted and converted into metal. This ore, after being crushed in a stamping-mill and washed, is brought into the roasting-furnace, which is of a similar form with those above-mentioned. Of this ore less can be roasted at once. A charge consists of about a ton of clean ore; it is put in a layer of only 3½ to five inches in thickness on the hearth-bottom. Under the influence of a gentle heat, a post of ore takes from ten to twelve hours hard work in stirring it with iron rakes; after which, some sulphur will still remain.

Calamine loses about 35 per cent. by calcination, and 40 per cent. of metal is obtained from the roasted ore. A ton of clean calamine requires five hours of roasting; it consumes half a ton of coal to a ton of ore, and requires the incessant work of three hands during this time. Blende requires twice that amount of coal and work to roast it. In general terms, we may say, that a ton of blende is worth about half as much as a ton of calamine to the smelter.

Silesian Process.—A large deposit of zinc minerals exists in that province of Germany which is called Silesia,—labor there is very cheap, and consequently, the metal is produced so cheaply, that most zinc smelt-works in other parts of the world are out of blast. In fig. 205 a vertical section of the Silesian reverberatory roasting furnace is represented; in which A shows the hopper for charging the raw ore; B B the apertures through which the stirring is done, and C, the furnace or fire-place. In fig. 206, the plan of the hearth, grate, and a section of the chimney is shown. About 1¼ tons of calamine are charged upon the hearth, which is 10 by 8 feet. It requires 5 hours' work to finish a heat, and 25 per cent. of fuel to the ore are consumed. The operation demands no particular care, nor skill.

FIG. 205.

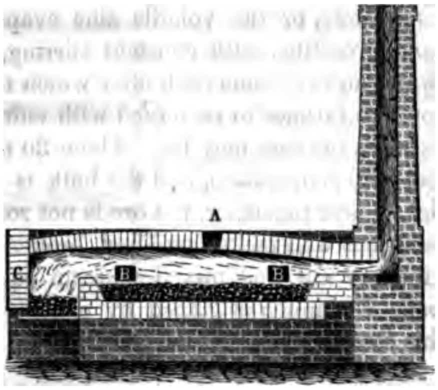
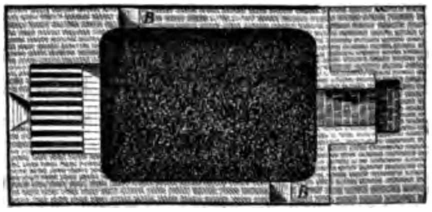


FIG. 206.



The ore when removed from this furnace, and cold, is mixed with an equal volume, about ⅔ weight of culm,—bituminous coal-slack—and this mixture is introduced into the previously heated muffles, which ought to be red-hot. The ore must be of course dry, or warm, to prevent a cracking of the muffles. From 55 to 60 pounds of roasted ore form a charge for a muffle. The muffles are flattened cylinders, made of good fire-clay, which is generally ground with fragments of baked clay, old fire-brick, or old muffles. These cylinders, which are from 3 to 4 feet in length, and 6 inches in diameter, are moulded over a pattern, and must be dried very slowly; they are then baked. This operation requires almost a week to complete it; and in order to prevent any cracking in cooling, the hot retorts are conveyed from the bake-oven to a reverberatoy, and directly charged with the ore. Five of these retorts are deposited in one reverberatory furnace for distillation. The plan of a furnace of this kind is shown in fig. 207. The grate is long so as to distribute the heat uniformly over the retorts, which are inserted through the opening B. These furnaces are generally double, with five retorts on each side of the fire. A high fire-bridge throws the heat against the roof, as shown in fig. 208. At one end the muffles are closed by a convex bottom, and at the other or front end, by an earthen plate or lid. The lid is provided with two openings, one near the bottom of the retort, and the other near the top; through the first the exhausted ore is discharged and also fresh ore charged; and through the latter the neck of the receiver is inserted. While the retort is in operation the lower opening is closed by a clay slab. The receivers are stoneware bottles, connected with the retort by curved necks. The furnace has no chimney, smoke and gas escape from B, which is walled up, loosely, by bricks for this purpose. These furnaces are provided with iron binders, to prevent any injury to them by expansion and contraction.

Fig. 207.

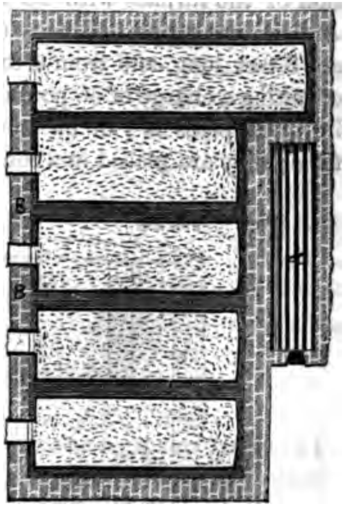
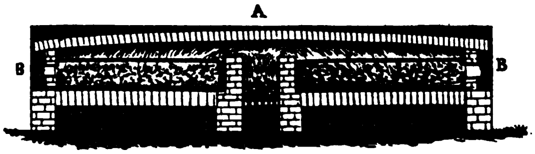


Fig 208.



The operation is conducted very slowly, at a cherry-red heat, in order to protect the retorts. One day is required for fixing a charge. In this manipulation, 1 ton of metal consumes from 6 to

8 tons of coal, and a new retort will last for the distillation of 1¼ tons of metal.

Liege Process.—This shows an apparatus somewhat more convenient for distillation than the above. In fig. 209, a vertical section of the furnace with its retorts is represented. The retorts A A A, are supported at one end by brackets of fire-brick. They are 3 feet long, and from 4 to 5 inches in diameter, and capable of taking a charge of 40 pounds of ore. The thickness of the clay in these pipes is ¾ of an inch. In one furnace there are 22 retorts; they are placed at a couple of inches apart from each other, to admit of the passage of the hot gases from the furnace B. The oven is in the interior 3 feet by 4, and 9 feet high; including the chimney it is 20 feet high. The back wall must be very strong, because it must support the stack. Over the retorts there is an arch, provided with some 10 or 12 small flues to distribute the fire uniformly. Fig. 210 shows a front view of the oven, with the arrangement of the retorts and the fire-place. The lower retorts rest directly upon the fire-arch, and receive the heat through a series of flues; the fire plays thus between and around all the tubes, and escapes at the chimney. An opening, with a door above the retorts in front of the oven, regulates the draft, by admitting more or less fresh air into the stack. The front ends of the retorts which rest on iron bars, are closed by lids into which

FIG. 209.

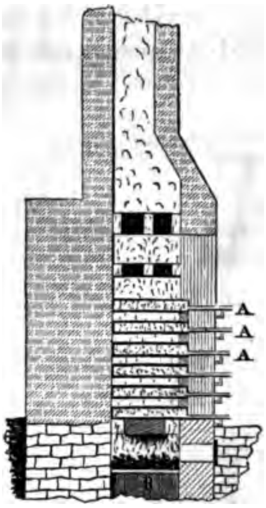
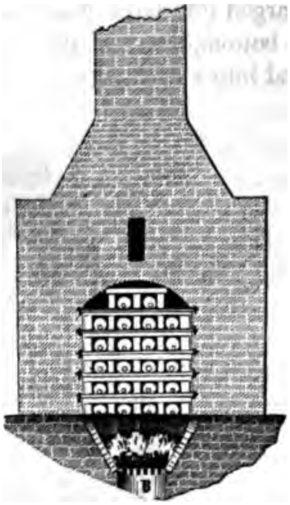


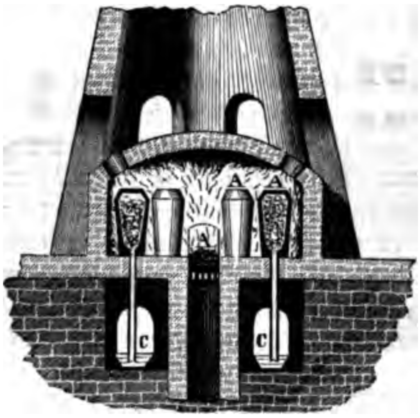
FIG. 210



cast-iron or sheet-iron receivers are fitted. These are conical pipes, of 1 or 1½ inch in width in the clear, and about 18 inches long, to which frequently an addition is made, according to the working of the retorts. The metal which condenses in these gently sloping pipes is raked out every two hours to prevent their being choked up; a blue flame issues constantly from the mouth of these pipes. Twelve hours are required to work off one charge, after which the retorts are cleared out and recharged. These ovens cause less labor than the Silesian furnaces, and are economical in the use of fuel.

English Process.—The original mode of distilling zinc in England was recommended by Watt. The mixture of ore and coal is charged into large crucibles, which are provided with a tube in their bottom, through which the liquefied or vaporous zinc is conducted into a cold receiver. In fig. 211 a vertical section of an English furnace is represented. These furnaces are sometimes round, sometimes square, and similar in form to a glass oven; six or eight crucibles, A A, are inserted in one furnace. The platform, or hearth of brick, is arched over with a cupola of fire-brick, which is provided with several flues, conducting the waste heat into a conical chimney, by which means the draught is regulated. In the rough wall of the oven there are as many large doors as pots in the interior, through which the pots are set; and through which they are removed when defective. Those which are made of fire-clay, are of considerable size, and after being previously heated in a separate furnace to ignition, they are put

FIG. 211.



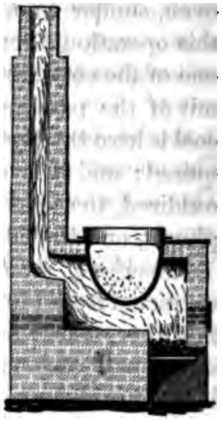
in by means of machinery, similar to that used for glass pots. B is the fire-place, and below it is the ash-pit. The pots are provided with a hole in the centre of the bottom, which is closed by a wooden plug, previously to being charged with ore and coal. The wood in charring forms a plug of charcoal, which prevents the ore from falling through, but admits of the passage of the metallic vapors. Below the pots there is a large vault, to admit of access to them. An iron pipe inserted into the bottom of a pot conducts the metal into a receiver, C C, filled with water. The pots are charged from above, through an aperture in the lid, by means of an iron tube reaching through the arch. The hole in the lid is stopped when a blue flame issues from it. The tubes below are occasionally cleaned by means of a red-hot iron rod, to prevent them from becoming filled with metal. The residue of ore and coal, after all the metal is exhausted, is discharged through the bottom. A good pot lasts from 3 to 4 months, and one charge takes from 2 to 3 days' time for exhaustion. An oven produces about 1 ton of metal each week, and consumes for that, from 11 to 12 tons of coal.

One smelter and two laborers conduct the operation; they make their own crucibles, and work alternately day and night. The expenses thus incurred for making one ton of metal, may be easily calculated. Pure calamine is generally expensive, and as one ton of metal requires on an average three tons of pure roasted ore, the cost of the crude metal may be estimated by these data.

The theory of the smelting process of zinc is very simple. The oxide of zinc mixed with carbon, is reduced to metal on being ignited; and the metal being volatile, passes in the form of vapor to the receiver, and condenses. The retorts or pots must be air-tight, so that no metal may escape with the flame. The coal used for mixing with the ore must be soft charcoal, or which is better still, bituminous coal in small pieces. Pittsburg coal would be best for this operation.

Refining.—The metal obtained in either of the above processes is crude; it is impure, mixed with other metals, and oxides of other metals. This crude metal is re-melted in large iron pots, lined in the interior with clay, to prevent the adulteration of zinc with iron. In fig. 212 a furnace and an iron smelting-pot are represented; three or more pots are generally filled for one fire. The cut annexed requires no particular description. The heat applied should be very moderate, and the metal is cooled by successive additions of cold metal to it. The lowest heat, and previously warmed moulds are required to make soft metal. In this operation, arsenic and other volatile metals are evaporated, while oxides, as those of iron, rise to the surface and may be removed. The purified metal is cast into moulds by means of hot iron ladles, coated with clay or loam.

Fig. 272.



Remarks.—All the zinc of commerce contains iron, lead, copper, cadmium, tin, and frequently arsenic, carbon, and sulphur. The greater the impurity, the more rapid is the oxidation of the metal, either by atmospheric influences, or by acids or alkalies. The Chinese metal is the poorest article; German zinc is hard; and, generally speaking, the Belgian zinc may be considered the best. English zinc is not in market. American zinc of prime quality has been exhibited, but we are not aware that any considerable quantity of it has been manufactured.

In distilling zinc, two distinct qualities are generally produced, which are kept separate. In the Liege apparatus, two condensing pipes are applied. The one nearest the retort is cast-iron, and in this the better quality is condensed in the form of grains. To this pipe a prolongation of sheet-iron is added and closely fitted; in it a metal of gray color condenses, which is more impure than the first, and separates from the pipe on striking it. The metal from the sheet-iron pipes is re-distilled in the retorts, but without the addition of coal; it is always an impure metal, even after the second distillation. It contains most of the impurities, lead, copper, and iron, and it is remarkable that these refractory metals are carried farther with the vapors, than the pure volatile zinc itself. The cause of this must be assigned to the influence of arsenic, sulphur, carbon, chlorine, and similar substances. Impure zinc, adulterated with a little lead and iron, is at a certain degree of heat more fluid than at a higher heat; it shows the same phenomenon as sulphur.

There is no absolute necessity for roasting calamine, but it is found more economical to calcine it before it is ground. The roasted ore is more easily crushed, and grinds finer. The latter operation is performed in a Chilian mill represented in fig. 174, and often ground as fine as flour. The calcined ore occupies less space than that which is crude, and works faster. It is tedious and expensive to remove the sulphur from blende, and various means have been advised and tried for the purpose, of which the cheapest is to expose the ore in large lumps to the heat of a roast-oven, similar in form to a lime-kiln. Little fuel is required in this operation, because the sulphur chiefly furnishes it; but it is one of the conditions that ore and fuel should be in lumps, to admit of the passage of air. Coke in lumps, or rather, anthracite coal is here the best fuel. In this operation only little labor is required; and if it should happen that all the ore is not perfectly oxidized, the light oxide of zinc is easily separated from the sulphuret, and the latter may be returned to the kiln.

Residue of the Distillation.—When the metal has so far been extracted from the ore as the fragile nature of the retorts will admit, there remains a mass composed of various metallic oxides, silver, and carbon. It is generally in the form of a powder, a little altered from the ore by heat, and contains zinc metal, and zinc oxide, iron and iron oxide, silicate of zinc, sulphuret of zinc, lead, copper, manganese, carbon, and clay, in various proportions. These substances are of little value, and are thrown away.

When ores of other metals, such as iron, copper, and lead, are smelted in blast furnaces, and they contain zinc, the latter is deposited near the top of the furnace as a rich pure oxide, in the form of a solid concretion, which in some instances accumulates to such an extent as to obstruct the passage. These concretions generally contain, besides the oxide of zinc, all those metals which are present in the ore, but generally in small quantities.

Rolling of Zinc.—This metal is extensively used in the form of sheets, and as these must be ductile, some caution is required in their manufacture. The metal to be rolled is cast in plates of one inch in thickness, in stone moulds. The plates are heated to a temperature between 230° and 300° before they are put between the rollers. The rollers,—which are of a similar form to those by which iron is rolled—are also heated; and zinc and rollers are greased with oil or fat. A small per cent. of lead added to the zinc, causes the sheets to be more malleable. When the sheets are reduced to No. 9 or 10 of the wire gauge, two, three, or four sheets are packed and pushed together through the rollers. During this operation the heat of the sheets should not change, and when finished, they are cooled slowly in a tempering oven. The production of zinc in Europe may amount to 20,000 tons.

Cadmium.—This metal, as well as zinc, does not occur native; and it is as yet doubtful if an ore of cadmium exists. Cadmium is always found accompanying the ores of zinc, some specimens of which contain from 2 to 12 per cent. of this metal. Blende always contains more cadmium than calamine; an ore of it, at Shelburne, N. H., furnished 3·1 per cent. As blende is a very common ore in this country, it may be worth while to pay some attention to this ingredient of it.

Cadmium is a beautiful metal; it has the color and lustre of tin, and is susceptible of a fine polish. It is soft, malleable, and soils the fingers or paper like lead; it is harder and stronger than tin, and produces the tin-cry like that metal. Cadmium is very ductile; it may be drawn into wires, or hammered into foil like copper; its sp. gr. is 8·6. It is very fusible, like zinc, but more volatile—in fact, it volatilizes at a heat at which mercury evaporates. Air does not alter it, but when heated it oxidizes and burns with a brown smoke.

Alloys.—Cadmium is very soft and malleable, and still all its alloys are brittle. Its combinations are not distinguished for fluidity. At those heats at which the alloys melt, cadmium evaporates. It has great affinity for mercury, and crystallizes with it. The combinations of platina, copper, and other metals with cadmium, are brittle and hard. The cause of these hard alloys from a metal which is in itself soft, must be found in its volatile nature and want of affinity. When it is melted with any other metal, there is a tendency on its part to evaporate. The slight affinity of cadmium for other metals, and its volatility, cause a separation of its atoms from those of the other metal, and no intimate union can be formed. If, therefore, the alloy cools, there are spaces between the crystals which have been occupied by the expanded atoms of cadmium, and in cooling, these are not filled again, this causes brittleness. We should not have alluded to these alloys of cadmium, if it had not afforded an opportunity to illustrate the nature of alloys. We see here that affinity and permanence are essential conditions in the formation of strong alloys.

Uses of Cadmium.—But little use has been made of this metal, chiefly because it is not found in so large quantities as to admit of its being manufactured on an extensive scale. Its combinations with oxygen, sulphur, or acids, have been employed in the arts to some extent.

Manufacture.—Since no particular ore of cadmium is known, the metal is obtained from zinc ores, zinc metal, or from the vapors which escape first in distilling zinc. The brown vapors which are observed issuing from a fresh charge of zinc ore, or zinc ore when exposed to roasting in the presence of carbon, are chiefly cadmium. These condensed vapors contain frequently from 10 to 20 per cent. of the metal. From such substances cadmium is extracted by acids and precipitated by sulphuretted hydrogen, and treated as zinc ore. In distilling zinc on the English plan, cadmium may be gathered in the condenser before any zinc appears.

CHAPTER V.

Manganese Properties.—This metal is not easily produced by itself; it is extremely refractory, and has a strong affinity for oxygen. It may be produced by mixing one of its oxides with lampblack and oil, and exposing it to the strongest heat in a coal-lined crucible. The metal thus obtained is not pure, it contains carbon. Manganese metal is soft and brittle; its sp. gr. is 7 or 8; it is very oxidizable, but slowly in cold, although rapidly in warm water, or acid water. It resembles iron, cobalt, and nickel very much, and combines with these easily; which may be caused not so much by affinity as a similarity in properties—particularly in their relation to heat, and melting. On the other hand, it resembles very much the alkaline metals; and in respect to forming slag, the most important office it performs for the metallurgist, it ought to be classed with the alkalies. It does not occur native.

Ores.—There is but one ore of manganese which is of practical use; and that is the binoxide, or hyperoxide, black-manganese. This is a black-brown, shining substance—amorphous—and contains, when pure, 63·6 per cent. of metal. The most valuable kind of this mineral is the crystallized variety, called gray manganese—pyrolusite. These ores are generally adulterated with iron, alumina and quartz, and contain water: sp. gr. 4·8 to 4·88.

Manganese, in a variety of forms, occurs in the United States—particularly in Vermont, Massachusetts, New Hampshire, Connecticut, Pennsylvania, Virginia, North Carolina, Michigan, Ohio, Missouri, Arkansas, and others. There are other native compounds of manganese, but these are of little practical application.

Alloys.—The only use made of manganese is in an alloy with other metals, particularly iron; and as it has a peculiar affinity for that metal, we observe it in most iron ores, and consequently in crude iron. It combines readily with phosphorus, carbon, or silicon, and forms with the latter substance an alloy which resists the attacks of nitro-chlorohydric acid—aqua fortis—successfully. We may here observe, that it is not the relation which the elements of an alloy bear to oxygen, which causes it to resist the attacks of acids, but the compactness of the metal. Manganese is as oxidizable almost as potassium, and silicon is easily attacked by oxygen. A compound of the two is as durable as gold, and is not touched by the strongest acids. We have spoken of this property of alloys before, and merely allude to it here as the opportunity occurs. Manganese melts with all other metals, and causes hardness. It imparts to iron whiteness, and causes it to become hard and brittle. It is found in very small quantities in good steel, not often in wrought-iron. A little iron in manganese improves its resistance to the attacks of oxygen, and causes it to be magnetic. We do not know if it may be combined with zinc, antimony, or lead; but suppose so, if the operation is performed under proper conditions.

Manganese is very refractory, and has a strong affinity for oxygen; its protoxide forms one of the most powerful bases in silicates with which we are acquainted—in fact, it cannot be reduced in the presence of silex. As the formation of slags is all-important in metallurgy, manganese becomes—if not as a metal, as an oxide—one of the most useful substances in smelting operations. In the progress of this work, we shall find many opportunities of alluding to it again.

Iron.—There are two distinct varieties of iron; one is a fibrous metal, or wrought iron; and the other, a granulated or crystallized metal; cast-iron or steel. These varieties of iron are subdivided, as we shall explain hereafter. All iron of commerce is impure; in fact, a pure article would not serve the uses to which iron is commonly applied. Pure iron is silver-white, of a very agreeable, mild, and at the same time brilliant lustre, and of a fibrous fracture. It assumes a high polish, particularly when rubbed with a hard, well-polished substance. Iron is easily tarnished; it has great affinity for oxygen, and acids dissolve it rapidly. Alkalies, in whatever form they may be, protect it remarkably well against corrosion; its sp. gr. is 7·78. It is the most tenacious of the metals, very soft when pure; but becomes extremely hard when alloyed with other metals, or any substance which combines chemically with it. It is singularly affected by magnetic currents; no other metal is more sensitive to that force than iron. Its susceptibility for oxygen, or it may be another cause, imparts a disagreeable taste to pure iron, when touched to the tongue. It also emits a peculiar smell when strongly rubbed. Iron has so great an affinity for other matter, that its existence in a pure condition is very doubtful; at least that presented by chemists, and obtained by them from wire-scraps, filings, hammer-scales, or similar means, cannot be pure. The only means of obtaining pure iron, is to reduce pure oxide of iron in a glass tube by means of hydrogen; but the iron thus obtained is in the form of a fine powder, and oxidizes when exposed to atmospheric air. When the heat in this operation is raised to redness on the oxide, before hydrogen is applied, the metal agglutinates into a gray porous mass, which is not much affected by cold atmospheric air. Another method of obtaining pure iron is by the galvano-plastic process. All experiments which have been made to obtain it, are indicative of its being infusible when freed from foreign matter; the degree of heat at which it is fused, increases with its degree of purity. In practice we have impure iron exclusively, and all our investigations are confined to alloys of iron; and as this metal is extremely sensitive to other substances, and as the kind of matter and the form in which it is present in iron, are conditions of its quality—and as further, this metal is the most important in our investigations, we shall enter somewhat into detail in this chapter.

Ores.—Iron ores are profusely scattered over the globe; and our own country has been abundantly supplied. If it is true that this metal exerts a peculiarly powerful influence in the advancement of the human race, the United States are under special obligations to Providence for His bountiful supply of it.

Native Iron.—Iron occurs in a native state. It is stated that a lamina of it was found in Canaan, Conn., attached to a mass of mica-slate rock. It has been found also in some parts of Europe.

But, although this may be as recorded, the native iron is so small in quantity as to be of no practical use. Native iron is also found in meteoric stones, which consist chiefly of iron and nickel; but these substances are of no interest to us. Iron combined with oxygen, carbon, carbonic acid, and some other substances, is the form which arrests our attention.

So great is the affinity of iron for other substances, that its ores seldom occur in a pure condition; and as the foreign matters form the quality of the metal smelted from the ores, it is evident that each peculiarity of the ore is imparted to the iron manufactured from it. Those minerals which contain at least 20 per cent. of metal, are considered ores; if they contain less, they are denominated fluxes. The richest and purest ores, are found in the primitive rocks. But as some ores, of more recent origin, form a metal peculiarly qualified for certain purposes, they are not less valuable than the former. Those minerals which constitute useful iron ores, we shall here proceed to notice.

Magnetic iron ore; loadstone, or, in simple terms, magnetic ore.—This occurs crystallized, and also granular, earthy, and compact. Its sp. gr. is 5·09. It is of a black color, metallic lustre, opaque, hard, brittle, and forms always a black powder, when rubbed or pulverized. It is attracted by the magnet, and is fusible in a very strong heat. When pure, it contains from 69 to 71·6 per cent. of metal. Some of these ores are hydrates, and contain 7 per cent. of water; and in this case, the metallic contents are diminished in ratio. Very extensive beds and veins of it are found in the counties of Warren, Essex, and Clinton, in the State of New-York. Imbedded in granite, syenite, and syenitic rocks, it occurs in Orange, Putnam, Saratoga, Herkimer, and other counties in New-York; in New Jersey, Pennsylvania, Virginia, Vermont, New Hampshire, Connecticut, Arkansas, Missouri, and we may add, in most States of the Union. No kind of ore is more generally diffused in the United States, either in larger quantities or better quality. The Swedish iron, so justly celebrated for its good qualities, is chiefly manufactured from magnetic ore.

The purest kinds of this ore furnish, by good management of the furnace, about 70 per cent. of crude iron; on an average we may calculate on 50 to 55 per cent. of metal. A specimen of this ore from Lake Champlain, furnished by analysis,

Protoxide of iron	17·9
Peroxide " "	81·8
Alumina and Silica	0·3

and a specimen from South Carolina 69·5, protoxide and peroxide, 1·5 alumina, 20·0 silica. The first variety may be considered a very pure, and the latter an impure, ore of it.

To this class of iron ores we may also range those magnetic ores which contain titanic acid. This substance is frequently found in the magnetic ores of New-York, amounting from 1 to 10 per cent. of them, and in single specimens even more. A specimen of ore from Lake Champlain furnished in 100 parts,

Peroxide of iron	70·00
Protoxide " "	12·31
Phosphoric and titanic acids	6·19
Silica	·36
Manganese	·33

This ore is also found to contain, frequently, iron pyrites, galena, blende, arseniuret, copper pyrites, heavy spar, and other more or less injurious substances. We shall allude to it again.

Red oxide of iron; peroxide of iron; specular ore; red hematite; micaceous ore. This iron ore occurs in nearly all geological formations, and the crystallized variety chiefly in primitive and metamorphic rock. It has been discovered, in late years, to exist in great abundance in the United States, and in immense masses at Lake Superior, and in the States of Missouri, Maine, New-York, Pennsylvania, Virginia, Arkansas, and others. This ore is also found massive, and as red ochre, combined with clay, shells, and other substances. Reddle is an impure kind of it. It is easily distinguished from other ores, by affording a red powder when rubbed upon a white substance; but as some of the varieties are very hard, and others feel unctuous, like graphite, a hard substance—white porcelain—is required to bring out the color. The crystallized varieties are generally pure and very hard, and may furnish 70 per cent. of metal; its sp. gr. is 4·5 to 5·3; the compact ore is 4·2. The crystals are of great lustre, brown, often black; the massive varieties are sometimes earthy and red, or brown-red. In thin laminæ, the ore is translucent, and of a bright red color. Some kinds of it are attracted by the magnet, which may be caused by particles of magnetic ore.

With this kind of ore are also classed the different argilaceous ores, which frequently are so poor in metal as to contain only 5 or 10 per cent., but are nevertheless of a perfectly red, often brown-red color.

The finest specimens of this ore occur in the immense deposits at Lake Superior, at the iron mountains in Missouri, and in Arkansas. Compact, and ochery-red ore, are found and worked in New-York, New Jersey, Maine, Pennsylvania, Virginia, and other States. All this kind of ore furnishes a superior quality of iron, which is distinguished for tenacity and softness.

A specimen of brown, or red-brown, fossiliferous iron ore, which is smelted in Pennsylvania, and Wayne county, New-York, contained,

Peroxide of iron	51·50
Carb of lime (shells)	24·50
Carb. of magnesia	7·75
Silica	6·00
Alumina	7·50
Moisture	2·75

On an average, these ores furnish from 36 to 50 per cent. of iron. Those which furnish less than 30 per cent. of metal are generally not smelted. Some of them, particularly those in the Southern States, are the result of the decomposition of pyrites, and the ore-beds show iron pyrites below the water levels. These ores also contain titanic acid, as is seen in some of the Pennsylvania ores; they are then very refractory. Alumina is the most general companion of these ores, and may be considered one of the causes of the good quality of the iron which they furnish.

Brown hematite; hydrated oxide of iron; brown and yellow ore; bog-ore; pipe-ore; prismatic ore. This is a very abundant iron ore, and a source of cheap metal; it forms the bulk of ore in this country. Hematite is essentially a hydrated peroxide, with definite quantities of water, which vary from 9 to 13 per cent. In its purest form it contains from 50 to 62 per cent. of metal. The varieties of this ore are very numerous; it occurs in all shades of color, from black to a faint yellow. The brown or black fibrous ore is of the best quality, but the compact kinds are more or less adulterated with silica and alumina, generally with the first. Bog-ore often contains from ½ to ¾ per cent. of phosphorus. Yellow ores are mingled with clay, lime, magnesia, and other substances; the brown ore often contains large quantities of manganese, from which no ore of this kind is entirely free. The powder of all the varieties of this ore is yellow.

All these ores are of recent origin. They are the result of the decomposition of pyrites, carbonates, arseniurets, and other compounds of iron, and often assume the forms of vegetable or animal remains.

It is impossible to mention all the localities where this ore occurs in the United States, but probably it is most abundant in the coal regions of Pennsylvania. Still, there is so much of it in the Union, that we do not wish to speak in favor of any locality. Ore of the best quality may be found at Salisbury and Kent, Connecticut, and at Amenia, New-York; a specimen from the latter place yielded peroxide of iron 82·90, silica and alumina 3·60, water 13·50, and a trace of oxide of manganese. Sp. gr. 3·8. Ore from Maryland yielded 86·32 peroxide of iron, 10·80 water, and 2·88 silica. Another from Maine, Aroostook river, 76·8 peroxide of iron, 10 water, 4.3 silica, and 8·2 manganese. The best kinds of this ore from the coal formations, which are generally the result of the decomposition of the argilaceous carbonates, contain on an average not more than 30 per cent. of metal. They generally are mixed with a variety of foreign substances, as the following specimen from Westmoreland county, Pennsylvania, shows:

Peroxide of iron	77·00
Oxide of Manganese	4·50
Alumina	·50
Organic matter	1·22
Water	12·00
Silica	4·00

Fine beds of the ore exist in Alabama, Tennessee, Kentucky, Ohio, and other States; in the two first the deposits are often extensive.

Sparry-ore, crystallized carbonate of iron. This is protoxide of iron in combination with carbonic acid. This ore most frequently contains also carbonate of manganese, and carbonate of magnesia. When perfectly pure, it ought to consist of 62·1 protoxide of iron, and 37.9 carbonic acid, which is equal to 48·3 parts of metal. The color of this ore is white, yellowish, and often of a reddish hue, or flesh-colored. There are also fine brown varieties, which may be considered partly oxides; and often the whole mass is thoroughly oxidized, and still retains its lustre and form of crystals. Its sp. gr. is 3·7 to 3·8; its lustre vitreous, and the streak or powder white. This ore is in some specimens translucent, particularly in thin scales. It is hard and brittle.

It is a very interesting species of iron ore; when pure it forms good steel with the greatest facility; in fact, it is converted into steel with less labor than into fibrous iron. German steel is exclusively manufactured of this ore, from the pure varieties of Styria and western Germany; for these reasons it is called steel ore. Notwithstanding this ore bears a high reputation as an element for the manufacture of steel, yet cheap steel can never be made from it, nor good steel, unless it is treated with particular care. But it is adapted to produce the strongest and most fibrous kinds of wrought iron, of which we shall speak hereafter.

This ore is very abundant in Europe, but not in this country; and to our knowledge, no iron of any amount is at present manufactured here from it. Some attempts have been made in the New England States to smelt it, but with little success. Sparry ore is found in Vermont; and that from Plymouth furnished by analysis,—carb. of iron 74·28, carb. of magnesia 16·40, carb. of manganese 6·56, and oxide of iron ·3. It also occurs to some extent at Roxbury. It is stated that a vein at that place is 4½ feet thick, and that the ore is converted into iron at a blast-furnace erected for the purpose. It is found in Massachusetts, New-York, and North Carolina; at Conrad Hill gold-mine, where it is mingled with gold, copper and iron pyrites, galena, and various other minerals. In Missouri and Arkansas sparry ore occurs, but it is not worked. This ore is most generally impure; it is usually mingled with pyrites, and sulphurets of various descriptions, which of course render the iron manufactured of it of less value than other and purer kinds of iron.

Argillaceous ore; compact carbonate of iron. This ore occurs chiefly in the coal formations, but its presence is not confined to these localities. When oxidized, it forms hydrated oxides, brown or yellow hematites; it is from these that the iron of Pennsylvania is chiefly manufactured. In its original form it is found in round or flattened lumps, spheroids, imbedded in clay, clay-slate, sandstone, shale, or limestone, and arranged in regular veins.

These balls range from globules of the size of peas to masses of two and more tons in weight; but as there are often large quantities of dead slate between the balls, the ore is expensive, however soft the shale may be. When the spheroids oxidize, the oxide assumes the form of shells ranged in circular layers, like an onion. It appears that the oxidation progresses either by periods, or, that at one time of the process more of the impurities are removed than at others, which causes a different density in the hydrated oxide, and a consequent formation of strata. This ore does not often contain more than 33 per cent. of metal. Its composition is that of the sparry ore, but it contains always some alumina (whence its name), and some silica, and lime. The ore, when dried or roasted, emits the peculiar argillaceous odor incident to clay and clay ores. Its color is gray, often yellowish-brown or blue. When in compact veins, it resembles limestone very much, in color and fracture, but is heavier and harder, for which reasons it is generally denominated limestone-ore in the western coal-fields. Its fracture is always close-grained. Sp. gr. 3 to 3·5.

This ore is not much used in its natural form, however extensively the oxide resulting from its decomposition is smelted. The extraction of it, occurring mostly in small veins of one to two feet in thickness, is rather expensive, and so long as its outcrops or beds, where the latter have been deposited, are not exhausted, our smelters will not be inclined to work the carbonate. Besides the expenses of raising this ore, those of roasting and smelting are always greater than for the hydrates.

A specimen of this ore from the anthracite coal region near Pottsville, Pa., furnished protoxide of iron 48·93, lime and magnesia 2·40, carb. acid 20·20, silica 23·75, alumina 2·25. The following is the assay of an ore from the western coal-field, Mercer county, Pa.,—carbonate of iron 84·24, carb. of manganese 1·33, carb. of lime 4·38, alumina ·89, silica 7·06, water 2·10. A fine quality of this kind of ore is extensively smelted in Maryland; it is found in the tertiary deposits near Baltimore, imbedded in a tough clay, in horizontal layers near the surface of the ground, and seldom extending to the depth of fifty feet. The ore, evidently carried by floods from the coal region, is found associated with well-preserved trunks of trees, and other vegetable matter. It is very pure, close and compact, and furnishes a superior iron for the forge.

The above-mentioned species form the only valuable minerals for the manufacture of iron in this country. Other compounds of iron, such as pyrites, arsenical iron, carburet of iron, phosphates, sulphates, chromates, muriates, titanates, and silicates of iron, are incidental admixtures to these ores; they never are smelted by themselves. All of them are more or less injurious to the quality of the metal.

In respect to the action of the ores in the furnace, they are generally divided into refractory and fusible. The latter are those porous, spongy ores, which easily combine with carbon and form gray iron; all the hydrates and some of the soft red oxides belong to this class. Magnetic ore, specular ore, particularly the crystallized variety, sparry ore, and the compact carbonates, are termed refractory ores.

Alloys of Iron.—Whenever alloys which are composed of other metals, are useful, those of iron are pre-eminently so. In fact, pure iron is a useless substance for all practical purposes, except the manufacture of steel. If therefore alloys must be formed to make this metal useful, the question naturally arises which of them are the most generally useful, and which are so only to a limited extent. When iron in its pure state is not suited for practical purposes, and we are compelled to combine it with other matter; and when it is extremely refractory, thus causing expense in working it, it is a question of great importance to the manufacturer to determine what kind of foreign matter to combine with it, in order to secure the greatest benefit to himself and to the consumer. The expenses of making iron are chiefly in its smelting and refining, and the benefit of economy must be sought for in these operations. Smelting is cheapest, when the metal and fluxes are most fluid; and the labor of transforming crude iron into wrought-iron is least when the impurities can be removed in the shortest time, and with the least labor. We shall here describe the nature of alloys, and allude to their application hereafter.

Iron and oxygen are not fusible at all; they do not assume a metallic form until they become a salt—such as magnetic oxide. Iron may combine with a little chlorine, which causes it to be fluid; but this renders it extremely brittle when cold. We have no other evidence of the combination of iron and chlorine, than that iron melted under a cover of chlorides is very pure, fluid, and brittle, of a bright silvery color and lustre. When this very fusible metal is gently heated, it is converted into very refractory iron—becoming fibrous and extremely tenacious. The melting of iron under a cover of chlorides is not so easily performed; it succeeds best when turnings of good gray cast-iron are melted by applying a very gentle heat, with a flux composed of common salt, lime, and alumina.

The affinity of iron for sulphur is very great; it is tedious to remove all the sulphur from it when once combined. Iron absorbs sulphur from all other metals, from fluxes, and from carbon. Oxygen or chlorine are the only substances which will remove sulphur, and before they enter into combination with iron all of it must be removed. The various forms of the legitimate compounds of iron and sulphur are of no interest to us. Small quantities of sulphur, ¼ of 1 per cent. in the metal, not only are injurious to iron, but cause expense and vexation in refining. Much sulphur in iron causes it to be cold-short, brittle and hard when cold; a little produces hot-short and brittleness when the iron is hot. Sulphur has a remarkable influence on iron; it is similar to that of cadmium. At low heats it does not cause fluidity; the iron assumes a mushy appearance, but is not fluid. When the same iron is heated to a higher degree it becomes perfectly fluid, white, and compact. Similar phenomena occur with carburets of iron; and we are inclined to conclude by analogy, that such is the case with all alloys, particularly where one substance is far more volatile than the other. When iron is combined with sulphur to such an extent as in pyrites, it is extremely hard; oxygen does not attack it, and strong acids do not affect it. When it contains only a trace of sulphur, it is far more liable to corrosion than pure or alloyed iron. This is another evidence of the truth, that chemical affinity has not so much influence in the corrosion of metals, as their compact close form. Sulphur is not attacked by oxygen, whereas iron is, and it requires the close cover of sulphur to protect it. When metals are mixed with the sulphuret of iron which have no particular affinity for sulphur—such as gold—the decomposition of the sulphuret advances more rapidly. It appears that in this case moisture finds access into the pores of the metal, which accelerates the oxidation. This electrical action, which is frequently observed in metallic alloys, arises in consequence of imperfect union; it is by no means a universal case. Iron appears to melt with sulphur in all proportions; but it either requires a certain amount to form a chemical union of perfect fluidity, or so high a degree of heat that a proper arrangement among the particles becomes possible. In the latter case, a union is formed which is not easily destroyed. When iron containing sulphur is heated red-hot, and suddenly cooled in water which is a little warm, a smell of sulphuretted hydrogen is perceptible, even when only a trace of sulphur is present. A quantity of sulphur in ore, coal or flux, which is so small as to escape the most skilful assayer, is sufficient to cause iron to be red-short.

Phosphorus and Iron.—Phosphoric acid is frequently found in iron ores; quite as well in those which are primitive as in those of the coal formations and younger ores. Phosphoric acid in contact with coal is converted into phosphorus; and as iron has strong affinities for phosphorus, we always find it in the metal if it has been in the ore or the fuel—particularly in gray metal. When white metal is smelted, a large quantity of phosphorus is absorbed by the slag as phosphoric acid. Phosphorus, unlike sulphur, causes iron to be very fluid even in small quantities and at low heats. Owing to this property, phosphorus is less vexatious when present in iron than sulphur. Iron with phosphorus is white, close, and compact; assumes a high polish, and is less attacked by oxygen than other alloys. It is extremely brittle, so that the least force will break it when cooled below 32°. Phosphorus will drive sulphur from iron, when the latter is present; still, they may be both in crude iron at the same time. Sulphur is removed before phosphorus can be evaporated. Iron which contains phosphorus melts easily, works well in refining, is easily welded, and is in fact very manageable.

Carburet of Iron.—We do not know if a carburet of definite proportions is in existence; gray cast-iron is a mere mechanical mixture, and so is steel. We are not acquainted with any carburet. It appears that the refractory character of carbon does not admit of an intimate union but under forced conditions. Carbon will liberate itself in spite of the affinity existing between it and the metal. Carbon unites with iron very readily in all proportions, from a small per cent. of iron in graphite, to a quarter of 1 per cent. of carbon in steel. The compounds containing much carbon are not fusible; they are mere black powders. It appears that iron cannot absorb more than 6 per cent. of carbon —gray or white crude iron—without losing cohesion. Iron with carbon may be soft when gray, but is hard when white. Gray iron is imperfectly fluid—limpid—at all times; white iron is mushy like a sulphuret, but assumes a perfect fluidity when heated to a high degree. There is a striking similarity between the combinations of sulphur and iron, and those of carbon and iron, which extends even farther than mere fluidity. White iron has all the qualities of a perfect alloy; gray iron that of a mechanical mixture. We will endeavor to show the nature of this difference. White iron, that is a perfect alloy, we do not observe but in crude iron which has been smelted from sparry ore, and in hardened steel. The intimate union of carbon and iron which is requisite to form an alloy is not in existence in gray iron, and in steel only when hardened. In white crude iron, sufficient carbon remains in union with the metal to cause its fluidity; this, for want of other matter, is chiefly effected by carbon. When more carbon than about six per cent. is removed from this iron, it ceases to be fusible in the furnaces. The carbon is naturally in very intimate connection in the specular ore, and the heat in smelting removes merely a part of it, and chiefly oxygen. A definite arrangement of the atoms of carbon and iron exists already in the ore, which is in a great measure destroyed; a certain portion of the ore however retains its original constitution, which with the difference of oxygen or these particles of carburet, are surrounded by a certain number of particles of pure iron which prevent their decomposition. Thus it is, that the carbon in this iron resists the effects of oxygen for a longer time than that in other kinds of iron, and also in steel; and to this extent we may call this iron a true alloy. It is the intimate contact of a few atoms of carbon, which imparts character to a large mass of iron. In gray iron, or tempered steel, the atoms of carbon fill merely the pores; and, if we assume that carbon is dissolved in hot iron—which we are permitted to do because similar cases happen with other substances—we at once discover the cause of hardening. It is the sudden contraction of the metal, and its strong cohesion, which condenses the carbon between its particles, and forces it to remain in chemical union. The strong cohesion in the atoms of carbon is the cause of gray iron; and the want of cohesion between the atoms of the latter, or want of fusibility, is the cause of the hardening of this metal by sudden cooling. We see here at once the philosophy of hardening and tempering, and that an alloy of arsenic or phosphorus cannot be tempered or hardened, because that essential condition, the separation of the particles, is wanting. Carbon crystallizes at a much higher heat than iron, and is solid; it also separates before iron which is slowly cooling has sufficient cohesion to prevent its crystallization. Carbon thus causes hardness in the same manner as other substances; and if we disregard tempering, or annealing, there are substances which impart a higher degree of hardness to iron than carbon. It appears that manganese induces the solution of carbon in iron more than other substances; still, there are some other metals which produce the same effect. Iron exerts a powerful influence on carbon at low heats and in the presence of other matter. It absorbs it and retains it as a black powder. This is the case in gray iron, and blistered and annealed steel. In strong iron, and gray iron of great cohesion, carbon is condensed into graphite and crystallized. We infer from these and other facts, that carbon exists in white steel, white iron, and in hardened steel, in the form in which we find it in the diamond.

Since we are upon the subject of hardening, we may be allowed to say a few words on annealing and tempering; the latter, of course, is a mere modification of the first. In exposing any alloy to a heat which may partially liberate some of the component parts, we afford them an opportunity to aggregate in their own peculiar form. And if the particles of the main body of the metal are not movable, the alloyed particles will assume forms of their own, separate from the metal, and it becomes porous; its pores are filled with the foreign substances. This requires that at least one of the elements in the alloy should have sufficient cohesion to assume a form of its own, which, of course, induces the others to do so. Carbon is pre-eminently qualified for this end, and generally performs it. Carbon is not necessarily required in all cases; tin effects the same in copper, and sulphur next to carbon in iron. It follows from this, that substances which are intimately combined with the metal, or which have not sufficient cohesion of their own, cannot separate; such an alloy cannot be annealed. This is the case with arsenic and iron, and some other metals. Iron in such combinations cannot be altered, but by the evaporation or oxidation of the substances. Silicon forms a very hard alloy with iron; it cannot be tempered when carbon is not present; but if such iron is exposed to a gentle heat, under exposure to oxygen, the silicon is oxidized and the most brittle metal may be converted into malleable cast-iron.

It is not material in such case how much foreign matter is present in a metal, if its cohesion is not destroyed.

Silicon—This substance appears to have as much affinity for iron as carbon; and if not found in so large quantities it is nevertheless present in all commercial iron and in the best steel. The general diffusion of silicon—or silex, silica—its presence in all iron ores, together with its strong affinity for iron, indicates as certain its presence in iron. Silicon, alloyed with iron, causes the metal to be very hard and brittle. All the iron smelted from silicates, in which the oxides of iron are united by fusion to silex, is extremely hard and brittle; more so even than phosphorus would make it. When crude iron is largely alloyed with silicon, it causes the wrought-iron, made of it, to be brittle and soft; it forms therefore the poorest kind of bar-iron. Half of 1 per cent. of silicon causes crude iron to be brittle; but iron may contain 10 per cent. and more of silex, and be perfectly malleable. The first is an alloy, the second a mechanical mixture. When silicious iron is exposed to a gentle heat—tempered in sand or iron ore—the silicon oxidizes and separates from the particles of iron and forms particles of silex, which do not combine chemically with iron. Here silex is in the same form as carbon in annealed iron. Berzelius relates that he assayed a specimen of perfectly malleable iron, which furnished 19 per cent. of silex. Fibrous wrought-iron may contain large quantities of silex, and be perfectly malleable and ductile, but when the iron contains in the mean time carbon, an exposure to a high red heat will convert the silex into silicon and cause the iron to become short and brittle. We shall allude to this subject again.

Aluminum.—We shall not allude to the alloys of Boron, Selenium, Tellurium, and some other substances, because these are of no practical value. Aluminum appears to have a beneficial, toughening influence on iron, and it is asserted that Wooty—East Indian steel—contains this metal as alloy. It is certain, that all iron smelted from clay ores is stronger than that smelted from any other kind of ore, particularly in the form of wrought-iron. Pure alumina combines readily with iron when borings of gray cast-iron are smelted with it. Such cast-iron contains, however, silicon and other substances, which interfere with the true character of the alloy. It may be difficult to form a pure alloy of iron and alumina, because a high heat is required, at which other substances, whose presence cannot be avoided, enter into combination. In fluxing iron and aluminum by a substance which has a strong affinity for both, so as to reduce the point of melting, pure alloy may be formed, provided the flux is volatile and may be driven off. Pure carbon, or arsenic may form such a flux. It is stated that iron alloyed with alumina is very hard and tough, and exhibits the nature of Damascus steel. This is a strong indication of the refractory nature of the alloy; it does not combine uniformly with the mass of the metal.

Arsenic.—This substance causes iron to be very fluid, hard, and brittle. One part of iron borings melted together with two parts of arsenious acid, form an arseniuret of iron, of definite constitution. The best manner to alloy iron with arsenic is by cementation, as we have shown already. Arsenic combines very intimately with iron; its alloy cannot be hardened like steel, nor can it be annealed. When the heat in melting this alloy is too strong, the arsenic evaporates rapidly, throwing out iron which burns with greater brilliancy than any other compound of iron. It burns in similar manner to a very hot zinc alloy, but with more vigor. Notwithstanding the great affinity between iron and arsenic, in cooling or crystallizing, both separate to a certain extent, but in a different manner than iron and carbon. When an arsenical alloy is cooled and polished it shows, on examination with a microscope, a mass of dark crystals imbedded in a bright white metal, which forms a regular net-work, filling the spaces between the crystals. We suppose the crystals may be iron, and a little arsenic, and the cementing metal chiefly arsenic with a little iron; these are conditions which exist in other alloys. If this alloy is tempered at a red heat, the arsenic evaporates, and causes the remaining metal to be extremely brittle. The same cause is active in hardening this substance. If the metal thus weakened by tempering or hardening is melted again it forms a coherent, hard, compact iron, but with less arsenic. This alloy, so long as any arsenic is perceptible, cannot be forged nor welded, it is hot-short, and cold-short.

We perceive here, very distinctly, the cause of brittleness, and some reflection leads us to the cause of hardness in this, as well as in all other metallic alloys. Arsenic is a strong solvent for iron, but its own weak cohesion cannot prevent the iron from forming large crystals, which, being held together by a cement of weak metal, do not adhere very strongly. This alloy may be compared to crystals of salt, which contain water of crystallization, and anhydrous crystals. The metal is consequently brittle, notwithstanding its high degree of hardness. If the arsenic were a less perfect solvent, the iron could not form large crystals, and consequently the mass would not be so brittle. Carbon shows the truth of this theory very distinctly. Iron and arsenic are brittle when hot for the same reasons. Arsenic in evaporating expands, and does not admit of close contact between the particles of iron; the latter are hard and refractory, their surfaces slippery, and of little cohesion; they cannot adhere together until the cause of fluidity is removed, that is, the arsenic evaporated. When we assume that all ultimate particles of matter are extremely hard, which must be particularly the case with those which have a strong affinity among themselves, that is, strong cohesion, we find the cause of hardness. If a substance is dissolved, and permitted to crystallize in the solvent, in the most compact, dense form of which it is susceptible, it must assume the highest degree of hardness. The more dense the solvent, the higher will be the degree of hardness of the crystals; because the first assists the latter in forming an intimate union. Diamond cannot be any thing else than melted carbon; its strong cohesion is the cause of its superior hardness. Carbon must be soluble in all refractory metals, and must have a similar effect upon them which it has on iron. It is the united cohesion of iron and carbon, which causes steel, or iron, to be hard; and it is the solvent power of arsenic which permits the particles of iron to join in such contact as to become hard. All substances of great cohesion must form hard bodies when permitted to crystallize in small particles, and form a close compact body.

The various phenomena exhibited by alloys, are more distinctly manifested in the combinations of iron than in those of any other metal, because of the universal affinity of iron for other matter, and because it has been so closely examined. The strong cohesion of the metal is the cause of the great difference in its alloys. There is no doubt, if carbon could be united with platinum, the alloy would show similar phenomena as that of iron, and perhaps to a higher degree.

Arsenic exerts a peculiar influence on iron; it causes cast-iron to be extremely brittle, but when removed from it by refining, and converting it into bar-iron, it is found to be exceedingly soft and pure. Most of that iron which furnishes the best cast-steel, is manufactured from ores which contain arsenic. We shall allude to this subject again.

Chromium.—Iron combines with chromium quite easily, and forms an exceedingly hard alloy, which is brittle. By converting crude-iron into bar-iron, all the chromium contained in it is easily removed. Chromium is very refractory, and consequently, we entertain serious doubts of the brittleness of the alloy of this metal and iron. Sixty parts of iron alloyed to forty of chromium, is stated to be very hard and tenacious, cutting glass equal to a diamond. Chromium, as well as iron, are both refractory, and, as the heat required to melt either is high, it is difficult to obtain the alloy without an admixture of other matter; to the latter must be assigned the brittleness which is asserted to belong to it. In smelting these metals, either from their ores together, or omitting them directly, in all instances their purity must be doubted. The only manner in which a considerably pure alloy is obtained, is, by melting filings of pure wrought iron, in a clay crucible, lined with the pure oxide of chromium and carbon; the first forms a second lining in the latter. The alloy thus obtained, is, according to our own experience, very hard, uniform and tenacious, and shows no signs of crystallization, when polished.

Titanium.—This metal appears to be so refractory, and has so little affinity for iron, that it will not admit of an union. An union is, however, effected in the same manner as between lead and iron, that is, by employing a substance which has affinity for both. We have no experience in forming this alloy, and the scarcity of the metal hardly admits of its practical use.

Zinc.—We have alluded to the combination of zinc and iron before. As cast metal the alloy is worthless, it never will obtain strength. In refining crude iron which contains zinc, the latter evaporates; and by perseverance, a fine tough iron may be obtained. In this respect arsenic is superior to zinc, it works with more facility. It has been proposed by Mr. Morris Stirling of England, to refine iron in the presence of zinc, by using it or calamine, to the amount of one or two per cent. in the puddling furnace. We do not doubt the effect asserted of zinc, in producing a bright, fibrous iron, but we doubt its forming a strong iron; our own experience has shown that no strong or cheap iron, can be thus manufactured.

Manganese.—The similarity of this metal with iron, subjects it to the same laws. It forms similar compounds. In combining with iron it causes it to be more fluid, and consequently, harder than it is naturally. This metal is one of the best alloys in combination with iron, which is to be converted into wrought-iron. It causes cast-iron to be hard and brittle; but this assertion must be taken with due allowance for the influence of other matter. The protoxide of manganese is a strong alkali, and forms a very fusible fluid slag with silex. In refining iron which contains manganese, the latter is oxidized before any iron is attacked by oxygen; and its strong affinity for silex removes the latter from the iron. No manganese is ever detected in wrought-iron. Crude iron contains it when smelted from ores in which it exists. In manufacturing wrought-iron, this substance is, on account of its alkaline and refractory nature, the most useful auxiliary. Its application as black oxide in puddling or refining iron requires some caution; of this we shall speak hereafter.

Nickel and Cobalt.—These metals, alloyed with iron, appear to exert a similar influence upon it. Nickel is found native and alloyed, in meteoric iron. This alloy has been little examined, and is, to all appearance, of slight practical use.

Antimony.—This combines readily with iron; the alloy is very hard and very brittle. It is useless. The oxides of the metals mixed, and melted with carbon in a crucible, form an alloy at a low heat.

Lead.—This substance does not combine very readily with iron, particularly when the latter is in combination with carbon. When contained in the ores of iron, it separates in the blast-furnace from the iron and forms a stratum at the bottom of the hearth. The crude iron thus smelted is extremely hard, becomes very fluid on melting, and works admirably well in the forge-fire and puddling-furnace, and makes a very tenacious, fine, bright, fibrous iron, of first-rate quality. The fluid alloy of lead and iron is of no practical use; when cast it is brittle.

Tin combines readily with iron, and both mix in various proportions, and form definite compounds. The alloy is always hard, and this hardness increases in proportion to the quantity of tin, until the latter is more than an equal part. This alloy is heavier than iron itself—of greater hardness and lustre; 57·9 of iron and 42·1 of tin is said to be an alloy particularly distinguished. Iron thinly coated with tin forms tin-plate. For this purpose a very pure tin is required, or at least a metal free from easily oxidized substances.

Tin added to iron in the puddling furnace, to the amount of $\frac{1}{2}$ or 1 per cent, causes a bright metal, which works remarkably well in squeezing and hammering. It forms a strong iron, malleable, neither red-short nor cold-short. The application of tin for this purpose is rather expensive; we may obtain the same, or similar results, by other means less costly.

Copper.—Copper has no marked affinity for iron, and combines with it only in small quantities. Still, $\frac{1}{10}$ of 1 per cent. causes iron to be red-short. Mixed to cast-iron, it causes cold-short. Wrought-iron with copper is stronger, when cold, than pure iron. Its oxides form very refractory silicates, which, together with its permanency under heat, is the cause of its adhering tenaciously to iron. For these reasons, it cannot be removed from iron in refining the latter.

Recent experiments which have been made in England by Mr. Stirling, show the utility which we may expect to obtain from alloys. A mixture of iron, zinc, copper, and manganese, is said to form an alloy similar to gold, in all external appearances. These, and alloys of iron, tin, zinc, antimony, copper, &c., are recommended as superior metals for axle-bearings, and various other purposes.

Mercury.—Iron does not combine with mercury directly; but when an alloy of iron, which contains a metal soluble in quicksilver, is brought in contact with it, a combination ensues. Alloys of tin and iron, zinc and iron, silver and iron, may be combined with mercury, and resist the charring heat of wood. It forms a hard, brittle amalgam, similar to that of antimony.

Silver.—Iron melts readily with silver, but the metals separate in cooking, and show the same appearance as arsenic and iron. The alloy is harder and stronger than that of arsenic. This compound oxidizes rapidly. A small quantity of silver, $\frac{1}{5}$ per cent., may be united with iron, and form an intimate union.

Gold.—This metal fuses easily with iron, and fine ornamental works in iron are soldered with it. It is too expensive to form practical alloys with iron. The same may be said of platinum, and the platinum metals. However valuable such alloys may be for scientific purposes, the metallurgist cannot make any use of them.

Uses of Iron.—It is not difficult to state the applications of iron; it is used every where under some one or other form. Every person knows its universal utility. It is capable of being cast into moulds, and formed into any shape; it is drawn into immeasurably fine wires, rolled into sheets thin as paper, or cast into frames of immense weight; kitchen utensils and dwellings are formed of it. It is indispensable to all active men; no food can be prepared without it, and no artisan can pursue his duties without it. It accommodates itself to all our wants, desires and caprices; it furnishes the needle, the plough, and the anvil, the anchor, the chisel, and the steam-engine. It is the only medicine friendly to human life, which is dependent upon its existence in the arteries of man.

Manufacture of Cast-Iron.—Before the smelting of iron ore is resorted to, it is most generally roasted. Few kinds of ore are exempted from this rule. The yellow hydrates, brown hematites, in fact all the hydrates, need no roasting; the red hematites, clay ores, compact and crystallized oxides, and the specular ore, may be smelted without roasting. Some magnetic oxides, silicates, and carbonates, are also smelted without this introductory operation. All those ores which contain sulphur, arsenic, carbonic acid, carbon, or are not sufficiently oxidized, ought to be roasted.

Roasting.—This operation has been generally described in Part II. Chapter II., and we have but few remarks to make here, and these relate particularly to iron. The operation is performed in the open air in heaps; and as most roast ovens have been abandoned, we suppose this method is preferable to that in ovens. At the same conclusion we arrive, equally as well, by deductions based upon the nature of the mineral, and the end to be accomplished. Magnetic ore should be roasted, if it is desirable to smelt carburretted iron, for this ore is too compact to admit of the absorption of carbon, and it must be made porous in order to form gray iron. It contains also very frequently iron pyrites, blende, galena, arseniuret, silica, and other substances, which it is necessary to oxidize. When specular iron contains pyrites, which frequently happens, it must be roasted. Sparry ore is to be roasted to remove carbonic acid. If these ores are pure, that is, free from sulphurets, a strong and rapid heat may be made; but when they are impure, a red heat, with a liberal supply of air and moisture, are requisite to succeed well. Impure ore, such as argillaceous ore, clay ore, or hematites, in fact all ores which contain silex, must be roasted gently and slowly at a low heat, and with a long continued fire. Ore which has been roasted must be red, friable, and porous. When black and magnetic, it is converted into magnetic ore, and will not smelt gray iron. When it has been too hard burned, it should be thrown aside, or mixed with well roasted ore in certain proportions. When white iron for the forge is to be smelted, little attention is required in roasting the ore; still that from roasted ore works better in the forge, and forms a stronger iron.

Most iron-works roast in heaps; and where coal is cheap, it certainly is the most economical mode of working the ore: but where fuel is high, the saving of it should be regarded. Half the fuel used in heaps may be saved by roasting in ovens. A ton of coal, or a cord of wood, will afford heat for twenty tons of ore, when roasted in large piles or heaps. In an oven one half, and in a well constructed oven one third of that fuel is sufficient to accomplish the work; and if the labor is considered equal in both cases, which in reality is rather in favor of the oven, the advantages of the latter are evident. When the quality of stone-coal, as it respects sulphur, is doubtful, wood ought to be used in roasting, for the affinity of iron for sulphur is so great, that it will absorb any which is not oxidized. In using the kiln for roasting, it is not advisable to mix ore and coal, because if the coal contains sulphur it will certainly adhere to the iron. In these instances it is the better plan to burn the coal in a separate furnace, and oxidize sulphur and hydrogen by a liberal supply of air, before it comes in contact with the iron ore. It has been proposed to use the gases from coke-ovens for burning lime, and we may with equal propriety and success roast ore by these means. In fact, the following method, of which a vertical section is shown in fig. 213, is based upon the principle of a good roast oven. Two or more coke-ovens are affixed to an ore-kiln, which may also serve for the burning of lime. These coke-ovens, of the description given in fig. 214, admit fresh air over the hot coke, and burn the gases, which enter the roast-oven perfectly. If sufficient air cannot be conducted through the channel over the coke, a few small apertures leading from below the coke-oven into the flue, and from the latter to the kiln, may be provided, which will effectually remove all difficulties in the way of a perfect combustion. These flues from the coke-oven to the kiln must be provided with dampers, in order to suffocate the fire, when the coke is ready for drawing. Instead of coke-ovens, plain furnaces may be erected, and any fuel burned in them which may be found profitable, among which wood is entitled to the first rank. The feeding and working of the kiln is very simple, and needs no explanation.

Fig. 213.

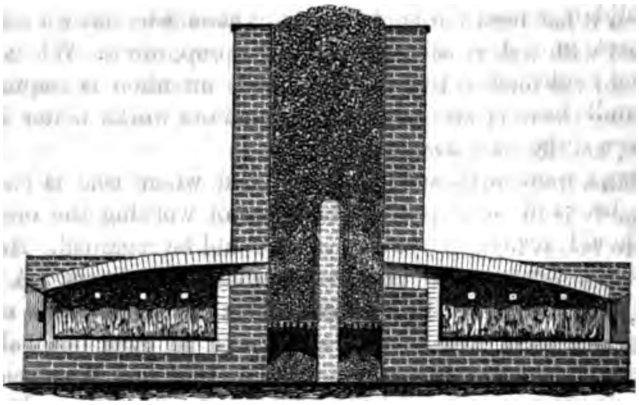
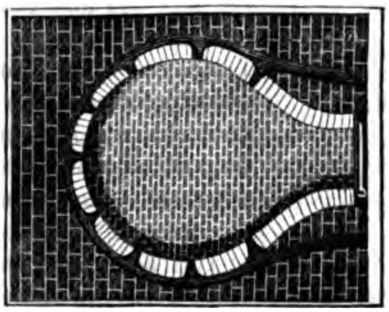


Fig. 214.



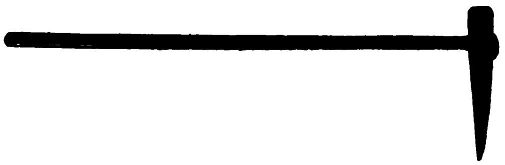
Those plans are not judicious which recommend the mixing of the fuel with the iron ore in roasting. It may be of little importance with other ores how the fuel is applied, but with iron it is of some consequence. No pure hydrogen, no sulphur, or phosphorus, ought to come in contact with iron ore; and if the fuel is mixed with the ore, such occurrences cannot be prevented. Hydrogen forms magnetic oxide, sulphur forms sulphurets, and other foreign substances are quite as injurious. When hydrogen, sulphur, &c., are perfectly burned before they come in contact with the ore, it is uninjured, provided there is no unconsumed carbon present. In the latter case, for example, sulphurous acid, which may have been formed in the grate, is decomposed, and the sulphur remains with the iron. Other impurities, such as sulphurets in coal, or ashes from wood or coal, are hurtful to the ore, and ought not to be mixed with it. For the same reasons, the trundle-head flame of a furnace cannot be used for roasting ore, even if the temperature is high enough. If the objections to mingling the ore with coal did not exist in respect to quality, they would be valid in respect to the quantity of fuel consumed. Fuel should always be burned in the highest attainable heat; this does not exist in an ore-pile or in a kiln, and cannot, because it would melt the ore. That which oxidizes ore to the greatest advantage is a cherry-red heat, which, in no case, can be uniformly maintained when the fuel is mixed with the ore. In burning the fuel in a separate furnace, leading the flame into a kiln, all the advantages of a perfect combustion, with freedom from the ashes of the ore, may be obtained. In this case, sufficient air, and even vapors of water, may be admitted with the flame of the fuel to reduce the heat to a standard temperature.

Whatever may be the means by which ore is roasted, it ought to be a peroxide in all cases. A black, melted mass of ore is like so much forge-cinder, and it will cause impure, short iron. If the ore is not sufficiently roasted, it is no better than in its raw state in the furnace. Time and a limited heat are required to roast well; and the lower the heat is, the more perfect will be the result. The crystallized carbonate, sparry ore, is one of those ores which will bear, and which requires, a high heat to oxidize it; still, the heat of the sun is sufficient to accomplish oxidation. It requires years to roast such ore by these means. Nevertheless, this process is still partially practised in those localities in Europe where the quality of the iron is an object. The argillaceous ore of the coal regions there is roasted in immense heaps for six or nine months to obtain a good article. Time is a powerful agent in this operation, to which many of our iron smelters fail to pay proper attention. When ore is to be roasted at all, every heap in the yard should be on fire, and the longer it is so, the better for it; the amount of fuel is thus diminished, and the quality of ore improved. Ore which is burned in small heaps, of fifty or one hundred tons, should have at least four or six weeks of continued heat; it is on this point that ovens fail, and it may be considered as the chief cause why they are so little used. The length of time may be in some measure compensated by fuel, but this does not extend beyond a certain limit; for when the heat is higher than a cherry-red, it ceases to oxidize. Ovens, therefore, ought to be large, or they do not work well. Some ore may be roasted in forty-eight hours, but it would be better if twice that time was occupied for it. Magnetic ore, and carbonates of any kind, should have, even in an oven, a continued heat during a week. The size of a roast-kiln is by these data easily calculated; when a furnace is to smelt sixty tons of iron a week, the roast-ovens should have a capacity of three times that amount of tons for argillaceous ore. A kiln of the usual construction is not often more than 18 feet high, and the interior forms an inverted cone of from 8 to 10 feet at the top, by 3 feet at the bottom; such an oven will not take more than forty tons of ore, and cannot furnish per diem more than six tons of it well roasted.

There is no difficulty in smelting argillaceous ores cheaply and to advantage, and to produce a useful forge-iron, provided the smelters keep a good stock of ore in the yard, not only for roasting, but for oxidation and lixiviation of the roasted ore in the atmosphere when cold. The latter operation is not less important than the roasting itself. Iron ore cannot by any means be purified by roasting only; certain substances, such as sulphates or phosphates, may be present, and certainly are if any of the elements of these acids have been in the ore. Such acids, which generally adhere tenaciously to the oxide of iron, are removed by water, and often by a large quantity of water only. Rain-water is the best solvent for such substances, and an exposure of the ore for a time to its purifying effect, is the best means to free it from such matter. Whatever may be the means by which roasting is performed, time, air, and water are necessary to do it well. Large clamps, heaps, are as profitable as ovens; and if they are well put up, and supplied with draught-holes and fire-chambers, so as to separate the combustion from the ore, they may work quite as profitably as kilns. Kilns ought to be in all cases kept in constant action, so as to preserve a regular supply of ore, and lose as little heat as possible. The common form of the kiln is generally an inverted cone, while our drawing, fig. 212, represents a right cone. The latter form secures more uniformity in heat throughout the body of ore, but it is suited only to coarse ore, of the size of a fist and larger. Small ore requires a wide top. Fine ore cannot be roasted to advantage in any oven; it is to be used raw or roasted in clamps. A kiln in the form of a right cone should have a partition below, as shown in the engraving, so as to limit the size of the grate.

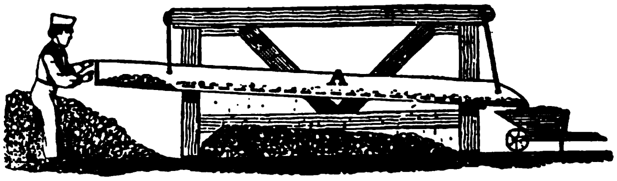
Cleansing of Ore.—Before subjecting ore to calcining, it is generally broken into lumps of a uniform size; if such is not the case, or if the roasted lumps are still too large, they are broken by means of a two-handed beetle, such as shown in fig. 215.

Fig. 215.



Machines cannot well be used for this. It is more expensive to carry the ore to one and back again, than to break it by hand. If the ore is hard, an ordinary oval limestone hammer is used. The size of the ore lumps depends partly on the kind of ore, but chiefly on the smelting-furnace and its mode of operation. When particularly good work is required of a charcoal-furnace, the size of ore is that of a hen's egg; at coke-furnaces we see lumps of four or five inches charged, and at anthracite furnaces any size which may be lifted by the workmen is not considered too large for the furnace. When good iron is to be made, the ore is riddled, to free it from fine dust, earth, and ashes. The means by which this is done is not important; a common sand or gravel riddle is frequently used, and we find also machines of the form represented in fig. 216. A frame-work is formed of scantling, about

Fig. 216.

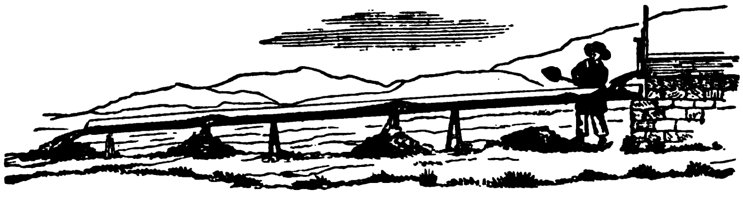


5 feet long, 4 feet high, and 2 feet wide, in which is a riddle, A, suspended nearly horizontally. The latter is formed of ¼ inch wire rods, with ¼ inch spaces, and suspended at the four corners on four rods, which move about the point of suspension. At the highest part of the riddle the ore is charged by shovelling, and a boy sets it in motion. The coarse ore rolls down upon a heap, or into a wheelbarrow, and the fine, which passes under the machine, is carried away to be washed, or thrown away. This machine is light, portable, and may be placed conveniently to the ore.

There is apparently no necessity of thus freeing the ore from fine dust, for these fine parts are in most cases the better portion of it. But dry, fine ore, will trickle through the spaces between the coal in the blast furnace, and arrive unprepared in the hearth, causing white iron, and often serious disturbances in the smelting operation, by producing a raw slag, or by accumulating in certain parts of the furnace and obstructing the blast, thus causing scaffolding. The evil resulting from fine ore has been effectually removed, at some of the furnaces in New-York State, by mixing the fine, granulated, magnetic ore with clay, and forming lumps of a large size, so that it may be similar to coarse ore. Besides thus improving the form of the ore, clay makes a natural as well as the best flux for magnetic ore; and an admixture of it would not do any harm in many other instances, particularly where rich ore is smelted. When a mixture of clay and ore is made, the first ought to be in a small quantity, and intimately mixed with the latter; any lumps of pure clay are extremely hurtful to the smelting operation.

There is no necessity for riddling all the ore which is used; only that part of fine ore which remains on the ground should be thus purified. The apparently worthless dust, and also the fine ore which remains in the yard after the removal of raw mine ore, is, in many instances, brought to the washing-machine, and liberated from those fine particles which may be carried off by water. Washing-machines of a variety of forms are in use, but that represented in fig. 217 is the most generally adopted, and may be considered equal in effect to any other apparatus. The grains of ore thus freed from clay are mixed with the coarse ore and smelted. Separating the fine dust from iron ore by riddling is a judicious operation, but washing away fine oxide of iron is of no use. There may be cases, such as washing raw magnetic ore, or raw hematites which are largely mixed with clay, but washing roasted ore will always include a loss of metal. Such fine ore may be tempered with water, dried, and broken into lumps. If clay or silex exists in the mass, the addition of a little slacked lime will cause the dried ore to be quite hard; and if pure lime cannot make it strong enough to resist the friction of coal in the furnace, a little clay-water added to it will effect it.

FIG. 217.



Fluxes.—We have noticed this subject, in previous parts of this work, and allude here merely to those fluxes applicable to the smelting of iron.

In practice we are limited to a few minerals as flux—limestone for silicious ore; and silicious clay, or other silicious compounds, for calcareous ore. When either lime or silex is in excess in any ore, the work in the furnace is imperfect—much coal is used, and labor wasted. One of the first maxims in selecting flux, should be that it contains an admixture of iron; and if such cannot be obtained, which is most frequently the case with limestone, an impure is preferable to a pure limestone. The leading principle in all smelting operations is, to smelt by as low a heat as possible. The oxidized elements which enter an iron blast-furnace do not melt by themselves, at least not at a low heat; a mixture, and an intimate mixture of ore and fluxes, is the most profitable condition under which smelting may be carried on. If these conditions cannot be realized absolutely, because it would be too expensive, they ought to be present to the mind of the smelter at all times, and his endeavor must be to approach them. Limestone does melt, but not pure lime; limestone mixed with silex melts more readily than when pure, and still more so when clay is present; and at a lower heat still when iron also is added. This principle we have explained before. An ore which contains all the elements requisite to melt at a moderate heat, and still is easily fusible after the metal is removed, is in the best form of ore, it works with the least fuel. If the latter condition is not complied with, or the residue of the ore fusible, it belongs to the refractory kind, and is expensive in smelting. The true theory of smelting is, to fuse the metal first, and remove it from the ore at a lower heat than that at which the impurities melt. All the metal should be removed before slag is formed. When these conditions are complied with, and the slag melts at a moderate heat, smelting goes on most profitably. In practice it does not happen very often that ores which act in this manner are found, at least not in large quantities. Bog ores, yellow and brown hematites, are sometimes found of a suitable composition. In the State of New Jersey, at Andover, a primitive ore is mined and smelted which affords flux in its own composition. These ores prove in practice the correctness of the above statements. Fluxes, of course, do not always consist of the same substance. If silex is the predominating or only foreign matter in the ore, limestone must be the flux; and limestone which contains clay, like some of that in the coal-formations, is preferable to pure or silicious limestone. If lime is present in the ore, and if it is the cause of resistance to fusion, silex or silicious rock containing clay, must be added in order to smelt the ore perfectly. Clay ores, such as frequently occur and are mined in the coal formation, do not work so well with pure limestone as with a silicious limestone. Iron, when present in these fluxes, no matter if they are limestone, slate, shale, or clay, has a beneficial influence; because it is in small quantities which cannot easily be removed, it causes the flux to melt and float down until it meets the ore, upon which it will settle and with which it will combine. It is easily perceived that when an incongruent mass of various infusible substances is brought in contact, it will require a long time, and consequently much fuel, before they are united. In all cases, one of the ingredients in the furnace ought to be fusible at a moderate heat.

It has been proposed, and experiments to this effect have been made, to mix all the necessary ingredients in a furnace, and melt them together before it is charged. After the explanations already given in this work, it is not necessary to demonstrate that such experiments must prove futile. If all the necessary substances were finely ground and formed into lumps and so charged to the furnace, there is no doubt they would work well, but in no other form. But this mode of smelting would prove too expensive, even if half the amount of fuel could be saved by the operation. A ton of ore or flux cannot be pounded fine for less than $1, which, together with mixing and burning lime, will add at least $4 to the present expenses for a ton of iron. Still, something advantageous might be done by these or similar means, in particular cases. There is no doubt fuel may be saved in such an operation, and the yield of a furnace increased; but it will entirely depend on the nature of the ore, and the facilities with which it may be crushed.

It has recently been suggested, and also asserted, that advantages are to be derived from using quicklime instead of limestone as flux. We do not doubt that the result of such applications may be beneficial in particular cases; but our own experience has shown, that quicklime is not generally favorable to smelting. Coal is saved in a small degree, but the quality of the iron invariably suffers more than the gain in coal can balance. All fluxes, as well as ore, ought to be porous and in the highest state of oxidation; we should be cautious before applying limestone in a calcined state. We shall allude to this subject again.

Artificial Fluxes.—Much has been said, and many experiments have been tried, on the application of artificial fluxes in blast-furnaces; that is, fluxes which do not occur as minerals, but are artificially prepared—such as common salt, potash, soda, and other substances. There cannot be any doubt as to the correctness of the principles upon which such applications are recommended; but the difficulty of applying them appears to be the chief obstacle. We know that admixtures to ore, which are present in so small quantities as to defy detection, impart a character to the iron which is smelted from it. The superiority of charcoal iron cannot be owing to any other cause than to the small amount of potash present in the charcoal. Still, we do not find potassa in the cinders of a charcoal furnace, nor do we find potassium in the pig-iron. There are on an average from one to two per cent. of carb. of potash in charcoal, and consequently in the iron, or slag, made by charcoal. Some of this alkali may be carried away by the waste gases at the trundle-head, but still, it cannot be entirely lost in that way. There must be small quantities of potash in the slag, as well as in the iron; or else it is all in the slag. The difficulty attending the successful application of such fluxes, must be sought for in the high heat and strong current of blast in the furnace. The first evaporates all such fluxes, and the latter carries them off—even when in combination with silex. The only way to bring such fluxes into successful use, is to dissolve small quantities in water, and soak the ore in such water. This will prevent evaporation to a certain point, but not altogether; for the application of such fluxes is unnecessary in any instance. In smelting by charcoal they are not needed, and in smelting by anthracite or coke they are useless; for the strong blast either removes them, or renders them inefficient. The materials charged in a blast-furnace ought to melt easily, but at the same time resist heat and force of current. By personal experiments we never found any advantage in applying such substances, and entertain doubts if any person ever did or will. The intimate combinations formed by nature we cannot easily imitate, at least not so as to make them available for practice.

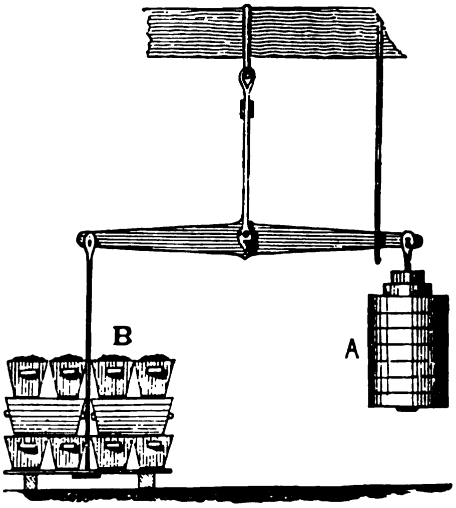
Amount of Fluxes.—On the amount of fluxes, not much can be said; a certain proportion of every principal constituent in the mixture of ore and flux is advantageous. The average of a good composition of furnace slag is nearly 40 silica, 20 lime, 12 alumina, 12 magnesia, and some oxide of manganese and oxide of iron; there are however others which answer equally as well. We shall explain hereafter the instances in which lime or silex must be added. This is altogether a practical subject, so far as particulars are concerned. No slag, or composition of ore and flux, can be determined *à priori*, nor with the assistance of the best assays of all the minerals in composition. We may come very near to the true composition, but not always to the definite quantities. Purely silicious ore, requires more limestone than that which contains silex and clay. Smelting by mineral coal occasions the use of more lime than smelting by charcoal; and by impure coal more than that coal which is not much adulterated with ashes. Fluxes should be broken into equal fragments of 2 inches for charcoal, and 3 to 4 inches for anthracite coal or coke.

Mixing of Minerals.—In order to insure regular and economical work in a furnace, the minerals should be mixed in certain proportions, according to the quantities of each kind which are at disposal. In this instance, as in others, it is true that the greater the number and variety of elements, the more prosperous will be the work. Six kinds of ore work better when mixed together in a furnace, than two kinds. One kind of ore does not work well; it requires much coal and is vexatious to the smelter. In mixing the ore a certain quantity—say fifty wheelbarrows full—are spread on a level floor in the bridge-house, in a stratum of uniform thickness. Upon this a stratum of a second kind of ore is spread; then a third, fourth, &c., all in ratio to the mixture calculated. On the top of this bed of ore, the flux is levelled in the necessary proportion. From this bed a charge, ready mixed, is weighed as it is wanted. At most of our furnaces this important part of the business is often left to careless hands, who take a certain quantity of ore from each kind, also some flux, and charge that into the furnace promiscuously. On the same principle that many kinds of ore work better together than each singly—and on the principle that the close contact of various particles of matter causes them to unite, or melt, at a lower degree of heat than when farther separated; for these same reasons the ore ought to be well mixed. It should not be placed in the furnace in heaps—that is, a wheelbarrow full of magnetic ore in one part, and half a barrow full of hematite in another place, and thus with the other kinds. If the fragments of ore and flux are all of the same size, the rule in mixing them must be, to associate together a certain number of pieces of each kind of ore, and add its ratio of flux. A charge composed of such uniform parcels, we may call a unit of the composition.

The method adopted at charcoal furnaces, is to fill iron or wooden boxes with ore, and weigh them as represented in fig. 218. On the side, A, of the balance-beam there is simply an iron rod with weights, which may be either of the common form, or cast in round plates. As many empty ore-boxes as must be filled for one charge, are placed on the platform at the other end of the beam. This weight is permanent, and only altered when found necessary in consequence of the working of the furnace. A certain number of boxes filled with the different kinds of ore, is thus weighed. By these means the ore is mixed in such proportions as may be determined by the smelter. One box generally contains from 50 to 75 pounds, and in some cases 100 pounds of ore. Flux is in such cases charged by measurement, or weighed on a second scales. This mode of mingling the ore is not so very objectionable, but still it is not sufficiently accurate, and it is laborious.

At anthracite and coke furnaces, the method is to fill them by wheelbarrows, and as the charges at these furnaces are heavy, there is little objection to this method of determining the ratios of ore, and also of flux. But the manner in which the ore is generally thrown into the furnace, is faulty. As we have already said, it cannot be expected that smelting should be performed to advantage, when ore of the same composition is put in separate parcels into a furnace. Let us suppose that a furnace with a wide throat, receives four wheelbarrows of ore, each of a different kind; and also a wheelbarrow full of flux. We know very well that no two ores melt alike at the same heat; and the very object of using a variety of them, is to make a mixture which will melt at a certain heat. If, in charging the ore, each is thrown by itself, and the flux by itself, the ore or flux which melts at the lowest heat will flow down into the hearth, and leave the more refractory ones behind. The advantages of a mixture are thus, if not entirely, at least in a great measure, lost. When one kind of ore is thus thrown on one side of the furnace, which is very frequently the case, and the furnace is worked by a number of tuyeres, one side will invariably work differently from the other. When we reflect on the nature of iron ore, and its action in the furnace, we are astonished that more disturbances do not happen to some furnaces. In all instances, no matter in what form the

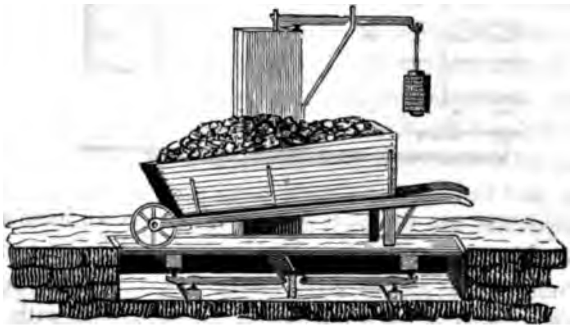
Fig 218.



ore is charged, whether by means of boxes or wheelbarrows, the most refractory material ought to form the lowest layer; this may be limestone or ore; and the most fusible should be at the top of the charge. We must remember here that the residuum of the ore after the metal is extracted from it determines its fusibility. A silicate of iron—forge cinder—is very fluid, but still it forms in most cases a refractory ore; for, when the iron is extracted from it, there remains a skeleton of silicious matter which does not easily unite with alkaline fluxes.

When ore is charged by means of wheelbarrows, these ought to be of similar weight, so that the same adjustment of scales serves for the different ones. The barrows are generally constructed of iron, as shown in fig. 219. They are pushed on a platform of the scales, which is level with the floor of the bridge-house, weighed, and emptied into the furnace. The form of these barrows is not always the same. The form represented above is not so common as the two-wheeled barrow, such as are used for carrying fuel to the furnace. We shall show this hereafter.

FIG. 219.



Properties of Cast-Iron.—Before entering upon the subject of the smelting of ore, we will point out some of the distinguishing features of cast-iron. It is not our province to explain the mechanical properties of metals. This belongs to the department of mechanics. We shall mention them only so far as they have any bearing upon the value of the metal. Crude iron, as it is known in commerce, is divided into three principal classes, namely, No. 1, No. 2, and No. 3. The first, gray-iron, constitutes the main body of foundry iron; No. 2 is used in foundries and forges; and No. 3 in forges exclusively. Crude iron is composed chiefly of iron, which is always present to at least 90 per cent., and not often to more than 97 per cent. Besides iron, there may be present silica, sulphur, phosphorus, arsenic, and manganese; in fact, all known elements, gaseous matter not excepted; for some crude iron contains nitrogen, which amounts in some instances to 1 per cent. Some of the admixtures of iron are in chemical combination with it, others are of a mere mechanical character.

Gray Pig Iron.—No. 1 foundry pig. However gray or often black this iron may be, it does not contain so much carbon as some kinds of white iron. It has been mentioned in the alloys of iron that carbon may be present in two, and even three distinct forms. The maximum of carbon in gray iron is not often more than 3·5 per cent., and the very darkest often falls below this mark. Some gray charcoal pig may contain 4·5 per cent. of carbon, but never more than that. The texture of this iron appears to be granulated; but by close examination it is found that the finest grain is formed of crystals, of larger or smaller size. In very dark charcoal or anthracite iron, we find these crystals often large and distinct. The fine grain or size of crystals depends, in fact, on the form in which carbon or other impurities are mixed with the iron. All chemical compounds are more or less white and brilliant, and show large crystals; and all mechanical compounds are grained, that is, show very small crystals. We cannot illustrate this subject better than by analogy. When alum, or any other salt, is mixed with a substance which dissolves in the same menstruum, water, and which combines with alum, we obtain a body of well-defined crystals in evaporating, or cooling. If we mix a solution of alum with carbon, or clay, or any finely divided substance, and evaporate it, we do not obtain large crystals, but an apparently homogeneous, granulated mass, which shows the color of the admixture. We obtain similar results in all cases when a body which crystallizes by its own cohesion is mixed with matter which does not unite with it chemically. Notwithstanding the inherent cohesive force is not entirely destroyed the body will crystallize, although the crystals may be extremely small. The same is true of iron. At a low heat—that is, a cherry-red heat—iron and carbon do not combine chemically, at least they separate in cooling when the latter is conducted slowly. At a higher heat carbon is dissolved in iron, and crystallizes with it. This explains the variety of crude iron. Gray iron is therefore chiefly a mechanical combination of carbon and iron; the crystals of the metal are often so small as to be imperceptible. This is particularly the case with iron smelted from argillaceous ore—as some of the Baltimore iron—and it is always an indication of a strong iron, more suitable for the forge than the foundry, provided it has been smelted by charcoal. Scotch pig has a similar appearance, particularly when remelted; but the quantity of other foreign substances present besides carbon, disqualifies it for the forge, however superior it is for small castings. Anthracite iron does not often show a fine grain; the best foundry pig shows on fracture large crystals of black iron. Similar to this is the dark-gray charcoal pig of the Western ironworks. The large black crystals are indicative of a strong, pure iron; for a weak iron, with much carbon, cannot form large crystals. The size of the grain may be thus made a guide to decide on the value of gray pig as a foundry metal. The darker the iron, the softer it will be; for the carbon is chiefly a mechanical admixture, and imparts its color to the metal. When black metal shows large crystals in the fracture, it is indicative of strong metal; for weak, impure metal cannot contract so strongly as to form large crystals. The mode of cooling the pig—that is, the material of which the pig-bed at the furnace is formed—has some influence on the color of the metal; a damp sand-bed will cause the iron to be brighter and not so black as it would be if cast in dry coal or coke dust, or a mixture of sand and dust. Notwithstanding all measures which may be employed to cause the iron to be dark, a weak impure iron cannot be made to show kish, or large black crystals. Impure iron never assumes a velvety black color, and the larger the amount of foreign matter besides carbon, the more the iron deviates from that color. This, of course, relates to soft iron cast in a dry bed, not to hardened or chilled iron. Gray iron is not so dense as white iron; its specific gravity is found as low as 7·, while white pig-iron may be 7·5 or 7·6.

Mottled Iron.—No. 2 pig-iron. This is either used for remelting in the foundry for large castings, or employed in the forge for wrought-iron. As a class it includes a great variety of iron, and it is almost impossible to form an opinion as to its quality by mere external examination. The fracture of this iron may be fine-grained, show large crystals, or be a mixture of both, as its name indicates. The form of the fracture depends in some measure on the manner in which it has been cast. Slow cooling in a dry porous pig-bed, causes grain; rapid cooling in chills, causes more decided crystals. In the same manner its color is affected; the first method produces a darker color than the latter. This iron may contain more carbon than gray iron, most generally it has less; still, there is no necessity of its containing less than No. 1. Nothing can be stated which indicates the quality of this iron for strength; not even the actual trial of breaking a pig, is indicative of its real quality. It may break very strong, and be weak after remelting or refining; it may break weak, and be the contrary. The quality of No. 2 crude iron depends on the manner of smelting, and, of course, on the ore. When a furnace is charged with much ore, and the iron smelted at a low heat, No. 2 iron is, or may be produced. When only a little ore is charged—that is, the furnace works by light burden—a similar iron in appearance may be the consequence. But, between these two kinds, there is a marked difference. The former is always purer, and, however short it breaks in the pig, will make stronger castings, and in all instances a superior bar-iron to the latter. We may state that the iron of heavy burden is of a more mottled appearance, than that of light burden; but this is by no means generally the case. This iron may show a very mottled fracture, and be as weak in the forge as in the foundry. The color of the iron is here, as in most other instances, the best means of judging of its quality, which, when guided by experience, may be relied on with some degree of certainty. Pure iron has a fine silver-white color, and rather less lustre than silver; carbon is black when free, but when chemically combined with iron it does not change its color materially. Good iron is composed of these two colors; any admixture of blue or yellow, any high lustre, is indicative of some impurities, which impair the strength of the metal. In this iron in general a part of the carbon is chemically, and a part mechanically combined.

White Iron.—No. 3 pig-iron, or plate-iron. The Germans understand by this term, a kind of iron which is not manufactured in this country—at least not to any extent; it is the iron resulting from the smelting of sparry carbonates. The only iron we can include in this class is white-pig and plate-iron from the run-out fires. It is asserted that this iron contains more carbon than gray or mottled iron; this applies to the above-mentioned German variety, but not generally to our white iron. We may state that, on an average, our white iron contains less carbon than the mottled or gray iron; which however must be taken with due allowance as to its mode of manufacture. Any iron, in fact any metal or substance whatever, which is chemically combined with another, forms crystals. White iron may contain little or no carbon, and show a perfectly crystalline fracture; but that iron which is crystallized with carbon only, is the best of this kind. We see here that no reliance can be placed on crystallization as indicative of the amount of carbon present. Such iron may be very impure, or may be of first-rate quality; the presence of crystals and absence of black spots, does not indicate any thing. Black spots show only that all ingredients are most intimately chemically connected. Sulphur, phosphorus, silicon, carbon—in fact, all matter has the same effect here in respect to crystallization. We doubt if any opinion can be formed on the quality of this metal, from the form of its crystals, because of the variety of matter which may be present, and which has a modifying effect on the forms of the crystals. In this instance, as in all others, the color and lustre of the metal is the only guide; white, with not too much lustre, is an indication of good quality. A colored iron, of high lustre, we may reasonably suspect of being impure.

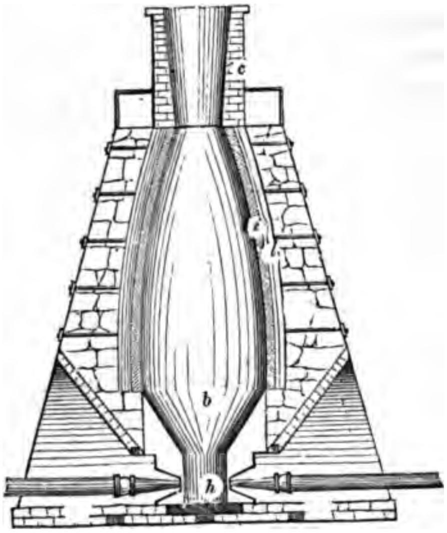
In conclusion, we will point to some general characteristics of the various kinds of crude iron. Gray iron does not become quite so fluid on melting, as white iron; but it retains its fluidity longer. When the crystals of iron are flattened and form spangles, the metal is generally impure and weak; strong iron crystallizes in columns, which incline to the octahedral form. These crystals are best observed by breaking a piece of iron when hot, or not cooled so far as to be black. Gray iron is generally soft, and white iron is hard; but when the latter is tempered, or annealed, as in the case of malleable cast-iron, it is as soft as gray iron. Hardness is not the result of cohesion only, or of a definite mixture; it is caused by both cohesion and crystallization. Therefore white iron may be perfectly malleable; this depends on the manner of cooling. Gray or annealed iron has less power to resist crushing than white iron, which has more than wrought-iron; but the resistance to torsion and rupture is very small in crystallized iron. Granulated iron is, in all cases, more malleable than crystallized metal. The average of contraction is about 1 part in 100, from the fluid to the solid cold state; this is however modified by the quality. Gray strong iron condenses more than gray weak iron, and white iron less than gray iron. With equal composition, gray iron requires a little higher heat than white iron for fusion. This fact can be inferred, *à priori*, from the nature of the compositions; a chemical compound melts at a lower heat than a mechanical mixture of similar composition. Cold cast-iron will sink in melted cast-iron, which is in conformity with a general law; but when cast-iron is heated to redness, it will float on molten iron. This apparent exception of a law of nature is caused by the difference in the specific quality of the composition. When cast-iron, or steel, is melted, or heated to a certain degree, the carbon is dissolved in the iron. In cooling, carbon endeavors to liberate itself and expands the metal; it is condensed again by the cohesive force of the iron cooling to a lower degree. When cold cast-iron is heated to such a degree that the expansive force of carbon is sufficient to overcome the cohesion of the iron, it will expand the metal; but condense again, on being chemically united, and absorbed by the fluid metal. This quality of carbon, or want of affinity below a certain temperature, is the cause of sharp castings; the expansion of carbon when the iron is yet soft, presses it into the finest pores of the mould, provided its surface is hot. This accounts for the superior softness of castings made in coal-dust, or sand mixed with coal—the surface of the metal is hot and will yield to the expansion from within; but when the surface is hard and chilled, the carbon and iron are forced into close contact, and in most cases form white iron. The process of annealing or tempering, may be, therefore, partially supplied by a bad conductor of heat, or a substance which generates heat—such as carbon or hydrogen. All castings made in carbon are softer and more gray, than those made in sand; which also are softer than those made in metal moulds, or in good conductors of heat. We observe here distinctly, that the mere compression, or force of cohesion, is the cause of hardness and crystallization. Cohesion may be effectually performed by mechanical pressure. When gray cast-iron is tempered, or annealed, it becomes soft and extremely brittle, which, when the iron contains much carbon, amounts to a complete annihilation of cohesion. Dark gray iron, annealed in a crucible under cover of carbon, becomes perfectly brittle, so as to be easily converted into powder. Gray iron, cast in coal-dust, or which is still better, bituminous coal-slack mixed with sand, becomes very soft and brittle. Gray cast-iron, provided it is pure, is not so much attacked by rust as white iron and wrought-iron. Sulphur disposes it to oxidize; so does silicon.

Before closing these remarks, we will allude to the advantages or disadvantages arising from chilling iron when it comes from the blast-furnace. It is in all instances advantageous to cast iron in chills, that it may be free from sand—particularly when it is to be used in the forge. Sand does no harm to foundry-pig; on the contrary it is better protected against oxygen when covered with it and a coating of protoxide, so as to prevent the access of air to its interior. In running iron into chills, it is suddenly cooled, and in consequence becomes hard, brittle, and is full of fissures. The finest steel loses its cohesion in hardening; the absence of sound indicates that no connection exists between the particles. Crude iron thus chilled in cold water becomes a mass of minute fragments, adhering slightly together, and subject to oxidation. Moisture penetrates such iron very readily. By these means some of the impurities are oxidized, and may be more easily removed in refining or puddling. The improvement thus obtained is but slight, and amounts to nothing in iron which contains phosphorus, or matter which is chemically combined with the metal. Carbon and silicon, metals which oxidize sooner than iron, may be oxidized in some measure by these means, and are then more easily removed. When crude iron is designed to remain a long time in the yard, it is, in all instances, a great advantage, so far as quality is concerned, to have it chilled.

Smelting.—This is an operation which is performed in the blast-furnace, as it is termed, because of its size and auxiliaries. In it the separation of the metal from the ore depends on the presence of heat, carbon, and the condition that the metal is heavier than the oxidized substances which form the slag. We shall not mention those old methods of constructing furnaces which possess a mere historical interest; but we shall notice those important modifications of the present apparatus which have a bearing upon the results of this operation. Blast furnaces are used exclusively in this country, for smelting fluid iron, and mostly gray iron. In some parts of Europe, a lump of solid iron is formed in the hearth of the furnace. But this is an expensive way of smelting iron, and not proper for imitation.

Fig. 220 shows a vertical section of a modern blast-furnace. These furnaces are from 25 to 50 feet high, and as wide at the base. In almost all instances, the bulk of the mason-work is constructed of rough stones. Sandstone is preferable, but any kind may be used except limestone. The furnace itself forms a pyramidal mass of masonry, commonly as wide at the base as the height from the floor to its mouth. The interior of the furnace is formed of fire-proof material, the lower parts of sandstone, and the upper of firebrick. The lower part, marked *h*, forms the crucible, or hearth, at which is the strongest heat, and where that part of the ore which has not been smelted in higher parts of the furnace is melted. This part is most commonly square, its sides are from 20 inches to 6 feet wide, and it is never less than 5 feet, often 8 feet high. The stones of which they are built in this country are exclusively sandstones, while in Europe, we find them constructed, not only of this material, but also of granite, gneiss, and even limestones; the latter, however, are becoming rare. Above the hearth *h*, the furnace widens rapidly and forms a gentle slope, *b* the boshes, where the furnace is gradually converted from a square to a round form. At the top, or widest part of the boshes, which varies from 8 to 18 feet in diameter, the horizontal section, of the interior of a furnace is a perfect circle, which is continued up to its mouth. We coincide with many of our furnace men in calling the receiving part of the furnace, its mouth,

FIG. 220.



instead of trundle-head, or tunnel-head, or some other unmeaning term. This round part of the furnace is most generally formed of firebrick, but in some instances of sandstone or shale. It has the form of an inverted cone, in which the sides are more or less curved. This part of the furnace, marked *i*, is termed the in-wall or lining. All those parts below the lining are solid stones, and closely joined to the rough-walls. The lining itself is not close to the rough wall; there is a space between marked *l*, from 6 to 8 inches wide, filled with broken stones, or broken furnace slags; these are loose, so as to admit of an independent motion of the in-wall, which is for these reasons made of firebrick. Rough stones expand and contract more than firebrick, and are more liable to fractures, and as injury to the in-wall may cause serious losses, the safest plan is to use good firebrick for its construction. The bricks are generally moulded in the proper manner for forming a circle; and are from 13 to 18 inches in length, which size decides the thickness of the in-wall. The in-wall rests on the rough wall of the stack, and is in many instances supported by heavy cast-iron beams, which form, in the mean time, the tuyere arches. The mouth of the furnace is, in some instances, very narrow, in others wide; this depends on the size of the furnace, kind of ore, fuel, blast, and management. The diameter of this throat varies from 20 inches, to more than 10 feet. In the majority of cases the mouth is provided with a cast-iron cylinder, which forms the throat. This cylinder receives the cold material, and is thus prevented from melting, or from injury. The top of the furnace is generally crowned with a chimney, *e*, as wide, or somewhat wider than the mouth of the furnace; it is provided with one door at small furnaces, and with several at large furnaces. Through these doors the smelting materials are charged.

At the lower part of the furnace we observe some arches, or recesses in the masonry of the stack. These are formed by dividing the basis of the furnace into 4 piers, as shown in fig. 221, and are called side-arches, H H, and back-arch, F, and work-arch G. These recesses are generally covered by semicircular brick arches, in few instances they are formed of cast-iron beams. The arches are from 8 to 16 feet wide, according to the size of the furnace. At large furnaces, a communication between these arches is effected by a gangway, I I I I, piercing the piers. The front or work-arch, often called tymp-arch, shows that the crucible is open here;

the discharge of the metal and slag is prevented by the dam-stone K, which is of a triangular section, bedded in fire-clay upon the bottom stone. L is the tymp-stone; it forms, by being raised from 15 to 24 inches above the bottom stone, the aperture for the discharge of the smelted matter, and affords ample space for the removal of any obstructions which may happen to be formed in the hearth. There are some peculiarities in the relative position of dam-stone and tymp which we shall point out hereafter. The tymp, as well as dam-stone, are covered with a heavy cast-iron plate, to prevent their being injured by charging heat. From the top of the dam, a gentle slope is formed for the discharge of slag which floats continually from the furnace. At the base of the dam-stone a small aperture, the tap-hole, is formed by cutting a part off from this stone before it is bedded.

Fig. 221.

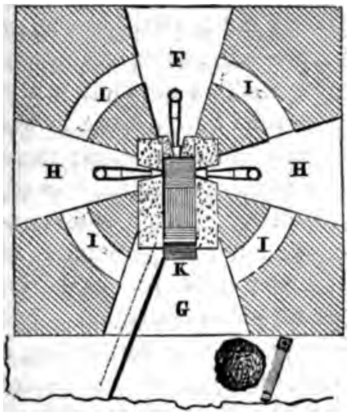
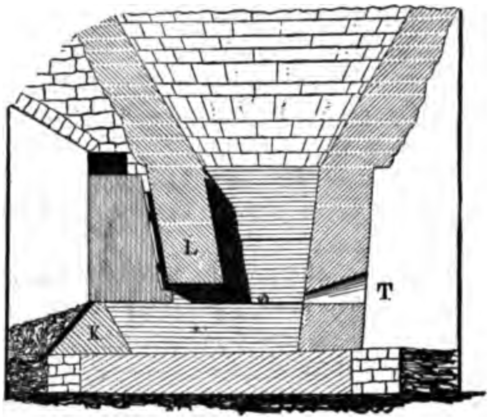


Fig. 222.

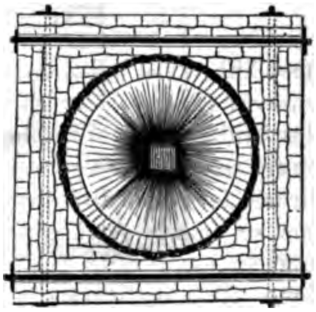


In fig. 222 an enlarged view of the hearth and boshes is represented, which presents all their parts more distinctly. It shows the principal joints of the hearthstones, and the manner in which the boshes are formed. These are, in small furnaces, constructed of a mixture of clay and sand, and in large charcoal, anthracite, and coke furnaces, either of firebrick or of sandstones.

In the plan here represented, the furnace is provided with three tuyeres, T. The blast pipes are conducted from the blast machine under the bottom stone of the hearth, and branches from it are led to the tuyeres. Small charcoal furnaces, which smelt from 20 to 25 tons of metal per week, work by one tuyere, from one of the side arches. Large charcoal furnaces are worked by two tuyeres, on the opposite sides; while anthracite or coke furnaces, generally have three, and some, five or six tuyeres. Conducting the blast pipes under ground it has advantages in respect to saving room, but it causes vexation in case any accidents happen to them; which often occur by using hot blast. It affords, however, in the mean time, the security of a dry bottom stone, which is of great value at any furnace. If the blast pipes are thus conducted under the hearth, they should be placed in a spacious channel, so that necessary repairs may be effected at any time. The bottom stone is laid upon a strong cast-iron plate, which covers this channel.

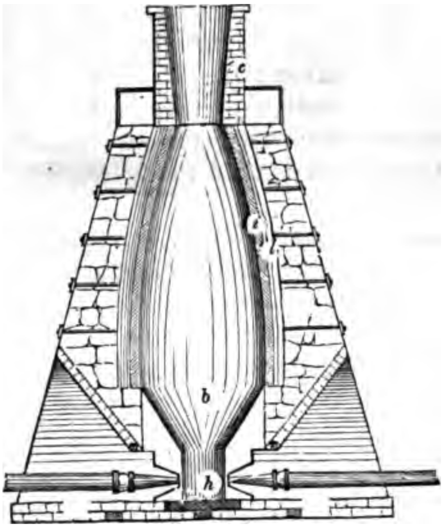
The rough walls of a furnace may be erected with little lime mortar in the joints; in fact, roughly laid stones appear to form the best stacks. When the masonry is well joined, and filled close with mortar, a system of air-channels is required to facilitate the escape of moisture which adheres tenaciously to any masonry. In all instances, a stack may be erected of hewn stones, bricks, or ore roughly put together; but a well-arranged system of iron binders is required to prevent a separation of the mason-work in consequence of the ever active expansion and contraction of the building materials. The mode of affixing these iron binders, or ties, is indicated in the various drawings; and more particularly in fig. 223, which presents a horizontal section through the widest part of the boshes. The particulars respecting the arrangement of these ties are subject to the discretion of the builder; but we may remark that there never can be too many binders in a stack. A large number of light bars is preferable to a small number of heavy ones. These binders are

Fig. 223.



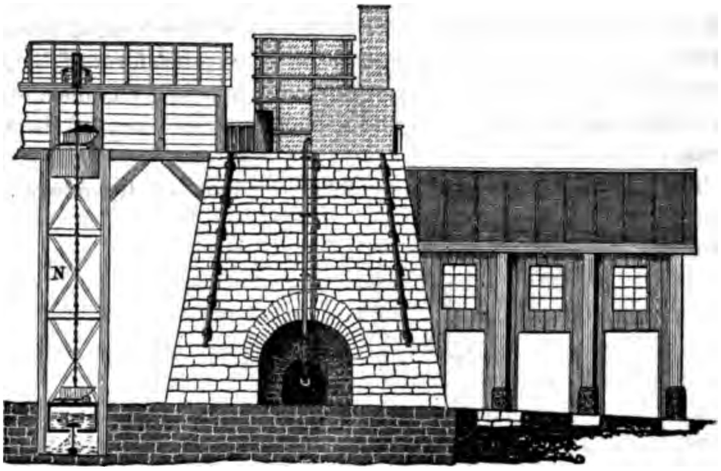
wrought-iron, generally square bars from 1½ to 2 inches, provided with keys at both ends, in preference to screws and nuts, which are not often used. Each end of a binder is also provided with a large cast-iron washer, which covers the channel as well as the stones nearest to the binder. As we have said, the form of these binders is generally that of a square bar; but a flat form of bars is preferable. These binders are located in spacious channels, so that they may be taken out, and mended in case any of them break.

Fig. 224.



The furnace represented in fig. 224, is located near the side of a steep hill. The hill and furnace are then connected by a bridge, constructed of wood, or in some instances of stones, or bricks. Upon this bridge a light building, the bridge-house is erected, which serves as a storehouse for fuel, ore, and flux, sufficient to feed the furnace for one or two days. Dry stock is thus protected against rain or snow. At large furnaces, no such use is made of the bridge-house, because it would require to be of too large dimensions. When a furnace is erected on a level place, or when no advantages can be obtained by locating the stack near a hill, which is decided by the mode of supplying the ore and coal, these materials are hoisted by machinery into a tower. Wheelbarrows, which contain the smelting materials, are pushed upon platforms and are raised by chains to the top of the furnace. In fig. 225, such an arrangement is represented. The tower N, is generally erected of strong timbers, and its top connected with that of the furnace by means of a wooden bridge. A platform is made, which forms in the mean time a cassoon, for the reception of so much water as will balance the load of ore, or coal. Two such platforms are suspended on a strong chain, over a rope-barrel, and when the lower platform is loaded, a current of water is conducted by means of leather hose, into the box, or cassoon, which forms the upper platform. When the amount of water, which flows from a reservoir placed at the top, together with the empty barrows, is heavier than the loaded platform below, the water is shut off, and the loaded platform ascends, while the empty one descends. When the cassoon with water arrives beneath, the upper platform is locked, and the water below is discharged by a self-acting valve, into a drain below the level of the floor. The rope-barrel is provided with a strong brake by which to arrest the machinery, in case an accident happens to any part of it.

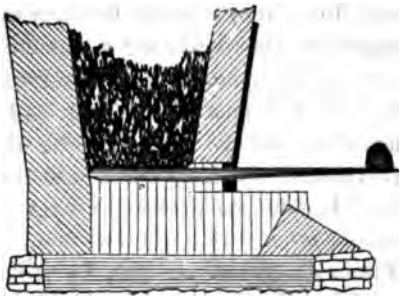
Fig. 225.



This machinery for hoisting is convenient, inasmuch as the power to set it in motion is easily applied, and always at the command of the workmen, provided the cistern is always supplied with water. At the furnace here represented, the hot blast apparatus is placed at the top. The cold blast is conducted upward, and the hot air down to the tuyere. Under this arrangement, considerable pressure in the blast is lost, which may be in some measure modified by employing wide pipes. At most furnaces which have been recently erected, both hot blast and steam-boilers, which supply the blast-engine with steam, are located on the top of the furnace. For these reasons, the area at the top is enlarged. The furnaces are thus made more massive, consequently there is less loss of heat by radiation from the furnace, and room for a large mouth. The hot-blast apparatus is, in these instances, located behind the steam boilers; it receives the waste heat when it has passed the boilers. In some instances the top flame is divided and partly led under the boilers, and partly into the hot-air stove.

Working the Furnace.—Whatever may be the dimensions of a furnace, or whatever kind of fuel or ore is used, the work is more or less modified by local circumstances. When a furnace is newly built, or has been out of blast, or has a new hearth put in, a slight fire is at first kindled at the bottom while the dam-stone is wanting. In order to protect the hearthstone against the immediate contact of a strong heat, it is lined with common bricks, which prevents the flying of these stones. The aperture formed by the tymp, bottom stone, and side stones, is walled up by common brick, and only a few small apertures admit of air for combustion. The hearth and stack are thus slowly dried, which may require from 3 to 10 days. When the hearth has been for some days thoroughly warm, the brick lining is removed, and it is filled to the top of the boshes with either charcoal, anthracite, or coke, whichever may be the combustible used for smelting. The tymp is open, in case the hearth is warm and dry; but when any doubt exists as to its being dry, ashes or sand is thrown on the coal in the tymp to prevent a rapid fire. In order to remove clinkers, which may be formed in the hearth, it is cleaned every 12 or 24 hours; and when the heat is strong, or an early starting of the furnace is contemplated, a grate is formed by means of ringers—long iron bars—as shown in fig. 226. Thus a strong draught is produced, a rapid combustion ensues, and the heat is augmented. If these bars are withdrawn after fifteen minutes or half an hour's time, the hot coal, descending on the clean hearthstones, will heat them thoroughly, and prepare them as well as the bottom stone for the reception of hot metal. One day, sometimes two or three days' heat, which time may be shortened by the repeated formation of grates, will prepare the hearth; the fuel has been, all this time, held as high as the boshes.

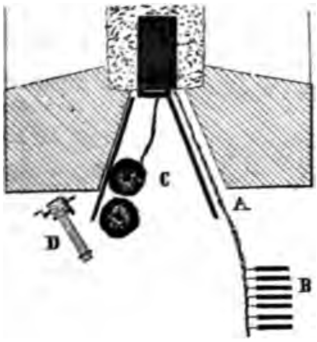
FIG. 226.



When thus far heated, the furnace may be charged with ore. In small charcoal furnaces, the coal is generally filled higher than the boshes; but in large ones, and those which are thoroughly heated, there is no need of having much fuel. The furnace is now regularly charged, alternately with ore and coal; the ore amounts to only half of a full charge, but the measure of coal is always the same. These charges are not made in rapid succession, but the flame is allowed to become visible on the top of the last charge before another is filled. The furnace is thus slowly fed by alternate charges of ore and coal; and, in order to facilitate the ascent of the gases, coarse coal is selected, or, when charcoal is used, brands or wood are mixed with the coal. When full to the very top, the furnace is ready to receive blast, and not sooner. Some founders usually let on blast before a furnace is quite full. This is imprudent; it causes disorder from the start. When the furnace is thus filled, the ore is drawn down by repeated gratings, which are so managed that the bottom is properly heated. When the first signs of slag, or iron, appear at the tymp or the tuyeres, the bottom is once more cleared of all adhering cinder, the dam-stone put in its place, and the dam-plate bedded in clay upon it. A large coal, or coke, or, what is better still, a mixture of fine damp coal and a little clay, is filled into the tap-hole; a stopper, or at first only heavy dust, is filled under the tymp, and the blast put on. At the first, only weak blast is used; in fact, for the next two or three weeks, the furnace does not receive full blast, in order not to injure the new hearth and in-walls by a too sudden and strong heat. A furnace is stouter with about half the pressure which it will take, and that gradually increased in the course of some weeks. A few hours' blast will raise the fluid cinder to the top of the dam-stone; the blast may now be stopped for a few minutes, the hearth tried by a light bar as to cleanliness, and if found free from clinkers or cold slag, a light stopper is formed of clay and coal-dust, the tymp shut, and the blast let in again. The melted iron accumulates now at the bottom of the hearth, and the slag runs over the dam-plate and is carried away. The furnace, of course, is perpetually filled with coal and ore, so that the materials are always level with the top. It must be a standard rule, never to blow a furnace by low stock, no matter how it works: it must be full. In cases of imminent danger of chilling, a sinking of charges is excusable, but only to be refilled by dead charges, that is, coal without ore.

It will require, according to the kind of furnace, from 12 to 24 hours to fill the hearth with iron. If possible, the iron ought to come near the top of the dam, before the tap-hole is opened for the first time. The tap-hole is generally at the right-hand side in the tymp-arch, near A, fig. 227. A channel,—run,—dug in moulding sand, conducts the iron to the pig-bed, B, where the pigs are previously moulded into sand or coal-dust, or dust of anthracite or coke, by means of wooden patterns. Running the iron into iron chills is not much practised. It is confined to only a few furnaces near Baltimore. If the iron is tapped before the pool is quite full, the hearthstones below the tuyeres are liable to be coated with a dry, tenacious cinder, which may cause serious vexation. Such dry cinders cause cold, white iron, and may occasion the freezing of the iron in the bottom. When the iron is thus tapped from the furnace, the blast is slaked, or stopped, the clinkers and cold cinder removed, and a fresh stopper of clay and sand placed under the tymp, and the blast put on again.

Fig. 227.

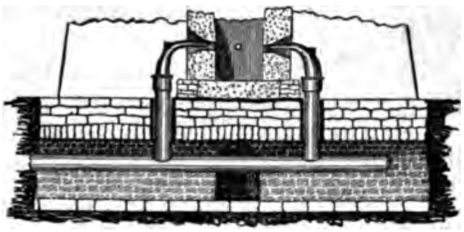


The first iron made should always be gray iron; for these reasons the ore charges are light. An increase of ore must be made gradually and very slowly, proceeding with the greatest caution as to the increase of burden. White or mottled iron, in the first week of a blast, is an indication of scaffolding the furnace. The fluid cinder thus formed is liable to adhere to the in-walls and cause troublesome concretions. When gray iron is smelted, the cinder is not very fluid, and may descend into the crucible before it becomes sticky, where the heat is strong enough to remove it at any time.

The tymp arch is divided into two parts, as shown in fig. 227. The run for the fluid iron is as much lower than the part C in the middle, as the height of the dam-stone. C forms somewhat of a slope, falling from the dam-stone gently. At the left-hand side are two cavities, into which the cinder runs alternately. About a ton of it is necessary to fill such a cavity with slag. A piece of pig-iron, or any other iron, is set vertically into the centre of the empty cavity, the cinder flows around it, by which it is firmly held, and, when the mass is nearly cold, it may be lifted by means of a crane located at D. It is deposited on a horse-cart, and carried away. The slope C is separated from the run A, and from the slag-trough, by cast-iron plates, set so close to both sides as to afford only sufficient room for either the iron or the slag to be removed. The room, or slope, thus formed, is necessary for the furnace-men to stand upon and work the furnace. In order to make this space as large as possible, the tymp arch is considerably larger than the tuyere arch.

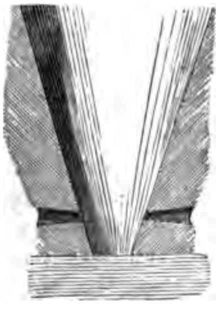
Remarks.—Having thus far given a general description of a blast-furnace, its construction and mode of operation, we will now take notice of some of its most important particulars. To commence with the bottom stone. This part of the furnace should be particularly dry, and, if convenient, even warm. A cold or damp bottom causes white iron and waste of fuel. In some parts of Europe, particularly in Sweden, the bottom is purposely kept cool; but not so in this country. It happens at some old furnaces that the foundation is not perfectly dry, for want of drains; but furnaces recently erected are well provided with means for the removal of moisture. Some kinds of ore, but chiefly the quality of iron smelted, afford the reasons for having a cold bottom stone; considering, however, the greater use of fuel incident to it, the advantages are in favor of a dry and warm bottom. The leading form should be the one represented in fig. 228, for the foundation of a furnace. A spacious arch-way crosses under the furnace between the pillars, so that a man may enter and examine it. Any moisture which happens to penetrate from above, which is often the case at hot-blast furnaces, thus subsides quickly, and cannot do much harm. In the mean time, it affords an opportunity of correcting the discharge of water, in case there is any obstruction. A damp bottom stone is not only the cause of waste of fuel, but it produces vexatious concretions of cinder below and around the tuyere, which cause much trouble to the founder. The bottom stone should be in one piece, if possible, but there is not much harm done if it is spliced, provided the joint is close, and the stone safely bedded. It should be a hard, well-dried sandstone, with a uniform grain.

Fig. 228.



The plan of the hearth is a square, and seldom round or elliptic; the dimensions of the hearth depend entirely on circumstances. A furnace in western New-York,—Siscoe furnace,—which melts a mixture of magnetic ore and hematites, principally the former, is 2 feet 10 inches wide, 18 inches high below the tuyere, and 20 inches above the tuyere, where the boshes commence. Such a low hearth is suitable for magnetic ore, spathic ore, and some specular ores, but it would not work well with hematites; for the latter kind of ore requires a higher hearth above the tuyere. The charcoal furnaces of Pennsylvania are not often less than 4 feet high above the tuyere. Ores which melt easily, or which are porous and form gray iron, ought to be smelted in a high hearth. The height of a hearth is regulated by the ore, but the size of it at the tuyere is determined by the fuel. A hearth for anthracite or coke is not higher than a charcoal hearth. For ores which melt with difficulty, a low hearth, in fact one where the boshes com-

Fig. 229.



mence at the tuyere, as shown in fig. 229, is considered profitable, and for porous hematites it may reach 1·5 feet above the tuyere. The space below the tuyere is generally plumb; above it, the batter is from $\frac{1}{24}$ to $\frac{1}{6}$, that is, one half-inch to the foot for very mild ores, and 2 inches to the foot for refractory ones. A high crucible has always more taper than a low one; and one for rich or refractory ores, more than one for impure and fusible ores. When forge-pig is smelted, the hearth is lower or more tapered than for gray or foundry-pig. The hearth should be wider, and have more batter, when much than when only a little iron is to be smelted. The height and batter of a hearth is in fact not of so much importance as is commonly supposed. It is expensive to smelt gray iron in a low or much-tapered hearth, and it is expensive to manufacture forge-pig in a high hearth. A high hearth always causes inferior forge-iron. The high crucible saves fuel and ore, but works slow. If we assume that a furnace without a hearth, where the tuyere is only 8 or 10 inches above the bottom, and the batter of the boshes drawn down to the tuyere, as shown in fig. 229, and also that a furnace of this construction produces the best forge-iron,—then regarding this as one extreme of the forms of a hearth, and considering the other extreme to be a hearth 6 feet high, and only half-inch batter to the foot, and assign to this the capacity of producing the best foundry-pig iron,—we shall have the intermediate forms nearly in the following order for ores. Starting with no hearth, or the lowest hearth, low pressure in blast, forge-pig, and much iron, the ores which may be smelted to advantage are as follows: raw sparry carbonates, raw magnetic ore, silicates and forge-cinder, raw argillaceous ore, crystallized peroxide, specular ore, compact peroxide, red oxides, roasted carbonates, roasted magnetic ore, roasted argillaceous ore, raw hematites, roasted hematites, pure bog ores, and bog ores which contain much phosphate. The series of ore inverted will work in a high hearth, strong blast, foundry-pig, and smelt slowly. Bog ore may be smelted in a low hearth, but not to advantage. As the ores are generally impure, a great deal of iron is lost in the slags, and consequently much coal is used; the yield is bad, and however good the iron may be in the forge, it is of no use in the foundry. If, on the contrary, we smelt refractory ore, commencing with the series, in a high hearth, the yield is poor, much coal is used, the iron never good for the forge, and not useful in the foundry. We thus see how much the form of a hearth is dependent upon a variety of circumstances, which must be considered in its construction. If we erect a cylindrical high hearth for smelting magnetic ore, and intend to smelt good forge-pig, and much of it, we certainly fail in the attempt. And if we desire to produce foundry-pig, of bog ores, in a furnace without a hearth, we shall find the iron very poor, weak, and hard, consuming much coal and ore in its manufacture, and not suitable at all to be worked in the forge. By considering these facts, we distinguish easily the correct form of hearth for certain kinds of ore, as well as quality and yield of iron.

Width of Hearth.—One side of a horizontal section of the hearth, or the distance between the tuyeres, is never less than 18 inches, and not larger than 8 feet. Round or oval sections of crucibles are not often used, and we shall not allude to them. The true measure of a hearth is the contents of the area, for which we assume one side of a square. These dimensions are somewhat controlled by the nature of the ore, but depend chiefly on the quality and kind of fuel, on the quantity and kind of iron to be smelted, on the pressure of the blast, and on the number of tuyeres. A hearth of only 18 inches square at the tuyere, which is worked by one tuyere, will make very little iron,—2 or 2½ tons in 24 hours. These dimensions are only suitable for working by weak blast, with half-pound pressure, and charcoal. In fact, all dimensions below 30 inches are for charcoal only. A hearth of 24 inches may produce from 3 to 5 tons per diem, with three-fourths of a pound blast and one tuyere; two tuyeres may bring the yield to 6 tons per day. A hearth of 30 inches may be worked by three tuyeres, three-fourths of a pound to one pound pressure, and produce from 6 to 10 tons of metal in 24 hours. The ore has much influence on the yield. A hearth of at least 30 inches, and from that to 4 feet in width, is used for smelting by coke, the yield of the furnace being in ratio to the size and amount of blast; it varies from 10 tons per diem to 16 or 17 tons. We find in anthracite furnaces,—the largest hearths in them,—the distance between the opposite tuyeres is not less than 40 inches, and sometimes it is as wide as 6 feet. An old hearth is frequently found to work well with a width of 8 feet. The yield in these furnaces varies from 10 tons per diem to 30 tons, according to size, ore, pressure of blast, and number of tuyeres. Large-sized hearths are generally of a round form.

Pressure of Blast.—The density of blast depends strictly on the quality of fuel, as has been detailed in the second part of this work, Chap. VI. It has been observed that soft charcoal works best with ½ to ⅝ of a pound pressure to the square inch; hard charcoal, with ⅝ to 1 pound pressure. The best wood-charcoal will not bear more than this density. Raw bituminous coal, or coke, is worked to advantage with 2½ pounds to 4 pounds pressure, and anthracite should have at least four pounds. We have no evidence that more density is injurious to the operation with anthracite. When less pressure than this is at our disposal, either from want of power or an imperfect blast machine, the width of the hearth should be reduced, to produce the necessary force of current in the fuel. When hot blast is used the densities are as above stated, but with cold blast they may be considerably increased. As the effects of hot blast may be in some measure produced by higher densities, the best results must, as a matter of course, be obtained when pressure and temperature are so regulated as to work the ore with the smallest amount of fuel. We are not informed what density of cold blast anthracite coal will bear; but we know that strong coke will bear 6 pounds, hard charcoal 1 to 1½ pounds, and soft charcoal to ¾ and 1 pound.

Number of Tuyeres.—The number and size of tuyeres depend on the size of hearth, the quantity of iron to be made, and whether hot or cold blast is used. In a small furnace, where charcoal is used and the production is limited, but one tuyere is used; and this is applied at one side of the hearth, as shown in fig. 230, and at the side of the tap-hole. It is a remarkable fact,

FIG. 230.

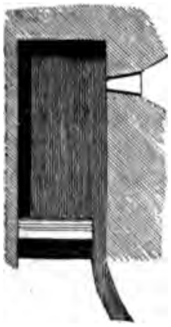
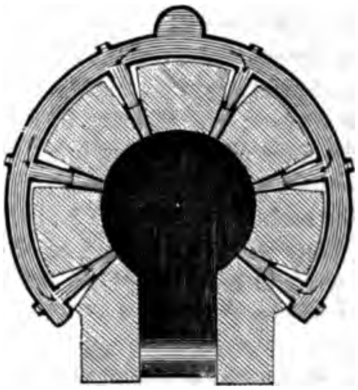


FIG. 231.

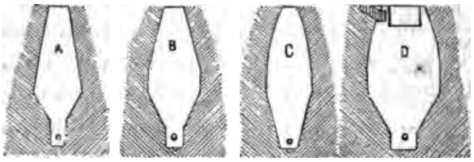


that all attempts have proved futile to work a furnace by placing the tuyere in the back stone, opposite the tymp. This appears to be its natural position, but in practice it does not prove so. Good coal, fusible ore, strong blast, and a well-sized hearth, will produce a large quantity of iron with one tuyere. Some furnaces smelt as much as seven tons per diem by these means. There are great advantages in working one tuyere, particularly with refractory ores and cold blast. All clayish and silicious ores work better with a single one. When a second tuyere is used, it is placed opposite the one shown above. At charcoal furnaces we do not often find a third tuyere. At coke and anthracite furnaces we find at least two tuyeres, and in most cases three; and sometimes as many as five or six. Then the section of the hearth is round, and the tuyeres are placed as shown in fig. 231. This arrangement is well adapted to work by hot-blast, but troublesome in using cold-blast on account of the cooling influence of the many apertures. Blast, strongly heated so as to prevent chills at the tuyeres, works admirably well by such an arrangement. A wide hearth and hot-blast will admit of the use of more tuyeres, than a narrow hearth and cold-blast.

Size of Boshes.—That part of the furnace commencing at the top of the crucible, which forms a slope more or less steep, the form of which varies very much, will be easily understood after the preceding remarks. The width of boshes, which means the largest diameter of the interior furnace, depends in some measure on the fuel, but chiefly on the quantity of blast which is brought to bear upon the fuel. The diameter, or rather the slope of the boshes, depends also on the kind of ore which is smelted. We may reasonably assume, that this slope is intended to perform a certain service; and that can be no other than gradually to diminish the force of the current of blast. As has been demonstrated in previous pages, the current of blast carries along with it particles of carbon, which may be either dissolved in the gases or not. They will be deposited, where the current or temperature is too weak to hold them longer in suspension. This fine carbon is absorbed by the porous ore. The size of the boshes must be, therefore, in ratio to the quantity of blast and the kind of fuel; assuming that both current and temperature are at the greatest diameter, so far diminished as to deposit the particles of carbon. If the boshes are too narrow for a certain quantity of blast, the point of depositing carbon is carried higher, and the smelting of the ore commences where it is liable to deposit refractory slag on the slope, causing scaffolding. If the diameter is too large, the ores are carbonized too low, and the slightest alteration of heat must inevitably deposit partially melted ore in the widest part of the boshes, causing concretions. In cases of doubt, it is preferable to have the boshes too narrow, rather than too wide; but we must be aware, that nothing has more influence upon the quantity of metal smelted than the dimension of the boshes. But if the furnace cannot be supplied with sufficient blast, it is very vexatious to have the boshes too wide. The extreme diameters in use, are from 7 to 18 feet. Charcoal furnaces will bear 9½, and in some instances 10 feet of width; but the latter is rather a large size. Coke furnaces are not often less than 12 feet, and do not work well if larger than 15 feet. Anthracite appears to afford a wide range; we find furnaces of 10 feet boshes, and also of 18 feet, or nearly four times larger. As the quantity of blast is in proportion to the fuel, and that in some measure controlled by the quantity of metal made, we find that the production of a furnace is nearly in proportion to the size of the boshes; still, this rule is not so perfect as to admit of correct deductions. The kind of ore and quality of iron smelted, exert almost as much effect on the yield of a furnace, as the size of boshes. Fusible, well-fluxed ore furnishes more iron; and a larger quantity of forge than of foundry iron may be made in the same time, by boshes of the same size. When the diameter depends on the quantity of blast, the slope of the boshes is regulated by the ore and the quality of iron smelted. A slope of 50° is commonly adopted in small furnaces where fusible bog ores are smelted; even 45° are not considered too flat. Raw ores, of the primitive formation, are smelted in slopes of from 70° to 75°, as shown in fig. 229. Between these two extremes we observe many varieties of slopes. Close, compact ores, which do not form gray iron, are smelted in steep boshes; and ores which are inclined to produce a gray fusible iron, may be smelted in flat ones. Foundry iron is better when made in flat boshes, and forge when made in steep ones. The yield of a furnace is greater in the latter, than in the former. The use of fuel is also greater in steep, than in flat boshes. This depends, however, so much on the form and composition of the ore, that in these respects little influence is exerted by the slope of boshes.

Form and Size of In-wall.—That part of the furnace commencing at the widest part of the boshes and extending to the top is always of a conical form, with straight, or more or less curved sides. By examining the use of this part of the furnace, we arrive at its correct form. In practice, we find it such as is represented in fig. 232, A, B, C, D. We shall not consider the

FIG. 232.



advantages or disadvantages of these forms of in-walls, but proceed to define the use of this part of the furnace. Assuming that the operation of reviving and melting the metal, and the slag, is carried on in the lower part of the furnace, from the largest diameter downwards—which is not always true, as we shall see hereafter—we discern the use of the space inclosed by the in-wall. Nothing is performed in it except the evaporation of water, and of gases from the ore and coal. In reducing the ore, these substances should not be present. Water as well as hydrogen, free oxygen, or nitrogen, are of no use in the crucible; the first and the second are actually hurtful. The object of this space, therefore, is to evaporate water from ore and coal without causing injury to the form of these substances. A high heat, of course, will evaporate water sooner than a low one; and it will also break coal and some kinds of ore, and form dust of them. For these reasons, a high heat at the mouth of the furnace, is often found to be injurious to the smelting operation. Charcoal requires at least 24 hours to dry it at a low heat; and some kinds of clay, or argillaceous ore, three times that length of time. When coal and ore may be dried in 24 hours, without injury to form, the size is sufficient when the capacity of the furnace above the boshes is sufficiently large to hold ore enough to work for 24 hours. When 10 tons of iron are smelted in that time, and 3 tons of ore and 200 bushels of coal are required for 1 ton of iron, the furnace must hold 30 tons of ore and 2,000 bushels of coal above the boshes. Generally we find the capacity somewhat greater; but there is no necessity of having more stock in the furnace, whether charcoal or anthracite. Where coke or raw bituminous coal is used, the case is different. This fuel contains always more or less hydrogen, the pressure of which is highly injurious in that part of the furnace where the iron is received. It requires a red-heat and a liberal supply of air, to expel hydrogen from a large body of coal; and also much time. In this case little can be done in 24 hours, and therefore such furnaces have a capacity for 3 days' stock. The form of the in-wall, if curved or straight, cannot therefore have much influence on the operation; but a gentle curve, or a cylindrical part above the boshes, is found advantageous. This will afford some play for the oscillations of blast, and prevent scaffolding on the slope of the boshes. The curved form shown in C, D, fig. 232, affords one advantage—namely, the same capacity with less height; and for this reason the curve is advantageous. It has been observed, that beyond a certain limit, there is no advantage in increasing the height of a furnace. This may be 40 feet for charcoal and anthracite, and 50 feet for coke or bituminous coal. A lower furnace works easier, makes better iron for the forge, and, when well arranged—that is, of sufficient capacity—does not consume more coal in proportion to the iron smelted, than a high furnace. It is, therefore, desirable to operate with the least height. This can be accomplished only by curving the lining so as to gain in the capacity. If this space of the furnace serves no other purpose, we may give any form we choose, without injury to the work. It has been proved by experience that the curved lining and a low furnace, work better than a straight lining and high stack. The curvature is, of course, never to extend beyond the largest diameter of the boshes.

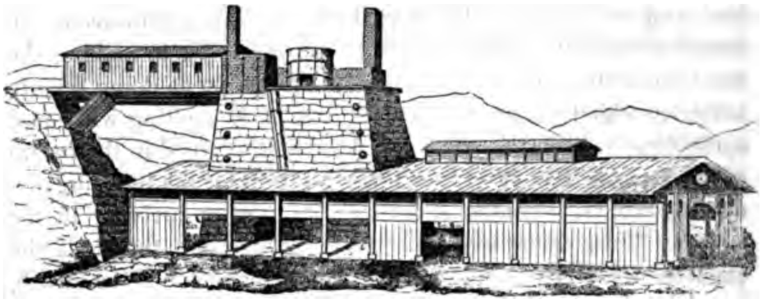
Size of Mouth.—On this subject a great deal of controversy has arisen without any satisfactory result. It is settled that narrow tops and too wide mouths cause a waste of fuel.

If we consider the object of this aperture, we shall be able to determine its size. The mouth is chiefly for charging the furnace with ore, coal and flux, and for the escape of the waste gases. If the current of the gas is too strong at the top, a large quantity of small particles of carbon are torn loose and escape, thus causing a loss of fuel. If the throat is too narrow, the ore is apt to bake and form lumps, which pass into the centre of the furnace and descend to the hearth unsmelted. A mouth of the proper size will cause some ore to move towards the in-walls, while the large mass will remain in the centre. When the throat is narrow, a marked difference is found in the operation of the hearth, when a fresh charge is thrown in, and when it is down. This is particularly the case at small, low charcoal furnaces. The oscillation in heat thus produced, causes a waste of fuel. A narrow throat will work hotter than a wide one, and thus cause the flying of coal and ore, which makes dust in the boshes and forms an obstruction to blast. There would be no objection to making the mouth as wide as the boshes, were it not that by so doing the ore is thrown chiefly near the in-walls, which in melting will cause scaffolding. And if in this case the ore is charged in the centre of the furnace, the waste heat escapes chiefly at the in-walls, preventing it from becoming sufficiently dry before arriving in the hearth. These reflections lead to the conclusion that half the diameter of the boshes should be nearly the diameter of the mouth, which is confirmed by practice. At charcoal furnaces the diameter of the mouth is generally made narrower, under an apprehension that heat will be lost. At coke and anthracite furnaces, we find the throat wider than half the diameter of the boshes; it ranges between ½ and ¾ of it. There is less danger of losing heat by a wide than a narrow mouth; the latter always consumes more fuel than the former, but it requires more attention on the part of the founder, because of its tendency to cause scaffolding. The mouth may be formed of an iron cylinder, or a brick wall.

The mouth is sometimes surmounted by a chimney; this is required to protect the workmen against injury from the flame. An open mouth causes improper filling, because the men sometimes cannot get near the proper place in consequence of the flame which is driven there by the draught or wind. It is in all instances proper to erect some protection for the fillers. A brick chimney, well provided with binders, and some apertures for charging, is all-sufficient for the purpose.

Blast-furnaces have in most cases, and should have in all cases, a roof over the top of the stack, a bridge-house, and a moulding-house. The necessity of these buildings is obvious for the protection of those who work the sand in the pig-bed, and the ore, coal, and furnace from the effects of rain and snow. The whole of a blast-furnace, including all these buildings, assumes then a form such as is represented in fig. 233. All these buildings should be constructed of iron, or coated with a fire-proof paint; for any losses in consequence of a conflagration in these establishments are of a serious nature, because they cannot well be covered by insurance.

FIG. 233.



Theory of Smelting Iron.—We recognize two distinct and active principles in smelting iron ore, or, in fact, any other ore. The one relates to those instances where porous ore is smelted; the other is that in which compact ores are reduced. In former pages we had occasion to allude to this subject, and remarked that carbon must be dissolved in the gases of the lower part of the furnace, or we could not account for gray iron. The carbon may be dissolved in hydrogen, or any other gas; it will be attracted by the oxygen of the ore, the pores of which it will fill if it is porous. By whatever means the carbon is dissolved, or set in motion, the effect must be in all cases the same. If ore is very porous, it will absorb much carbon and form a black or brownish-black mass, which is more refractory than pure ore, and which melts only in the high heat of the crucible. This condition of the ore in the furnace has been proved by actual experiments. In drawing out the contents of a furnace, when in the best condition for smelting, the ore was found to be in this state. Under these circumstances, iron is smelted with the smallest amount of fuel, gray iron follows with the greatest facility, and good quality can be depended on. This mode of smelting can be practised only on porous ores, bog ores, hematites, soft red oxides, and roasted ores. It requires a large space above the boshes in order to saturate the ore with carbon, and flat boshes to concentrate the heat below them and in the centre of the furnace; it also requires a highly charred fuel, which is free from hydrogen. It has been observed, that when it is desirable to smelt gray iron, raw fuel or imperfectly charred-fuel does not facilitate the operation.

On the contrary, raw fuel leads to the formation of white iron. Gray iron, of course, is smelted by raw bituminous coal, and also by wood; but we speak here only of ordinary circumstances, in which the fact is as we state. If the medium in which the carbon is dissolved, is indifferent in respect to the formation of gray iron, carburetted hydrogen ought to be particularly suitable for the formation of it. But this is not the case. Fuel which contains hydrogen forms, at best, an impure iron; and if gray, it contains but little carbon. Carburetted hydrogen certainly deposits more carbon in the ore, than can by any other means be accomplished; but hydrogen reduces many substances, such as silex or lime, which are not reduced by carbon except under peculiar circumstances. When hydrogen penetrates oxide of iron at a low temperature, it forms a powder of metallic iron, which does not so readily combine with carbon as a powder of oxide of iron exposed to the same degree of heat. We discern thus very readily the means by which gray cast-iron, of good quality, can be formed.

In these remarks we have alluded to one extreme—that is, the formation of gray iron from porous ore; we shall now examine the other, or the formation of white iron from compact ore. The best material to serve as an illustration, is a silicate of iron. When forge cinder is charged to a blast-furnace, it cannot absorb carbon in its pores; for it is compact and not accessible to any gas, so far as its interior is concerned. This substance will move unaltered in the furnace, to a point where the heat is strong enough to melt it. Here it is converted into a fluid cinder, or slag, and trickles down through the hot coals; these absorb oxygen from iron and other metals, and if the height of the column of hot coals is sufficient, all the iron may be reduced before the fluid slag arrives at the tuyeres. No carbon can be absorbed by the iron in this case; for it forms large globules, and is not in a condition, or not in so close contact with the metal as to combine with it. The fluidity of the metal is in this case most generally produced by substances which are nearest to the iron; and as these are phosphates, sulphates and silex, their respective bases will combine with the metal, which, when once fluid, does not absorb carbon, but rapidly descends into the hearth. In this case we perceive that a certain height of a column of hot coal is required to reduce the oxide; if that column is too low the iron arrives, in the form of oxide, at the tuyere, and cannot be converted into metal but by the presence of gray iron in the pool of the crucible, the carbon of which will reduce the oxide which may be in the slag. The height of the column of hot coal required, will depend on the nature of the ore. If it is a very fusible silicate, such as forge-cinder, a considerable height is necessary, because it will descend rapidly and escape the action of carbon.

In thus analyzing the operation of a blast furnace, we see that, in the one case, a very low column of heat, and in the other a very high one is required. Between these two extremes, we find the proper height. Very porous bog ores containing phosphorus, smelt in a narrow, almost cylindrical hearth 5 feet in height; a red heat is hardly perceived at the boshes. Forge cinder, by itself, requires at least a column of 25 or 30 feet in height of a red heat; and thus high the crucible ought to be, in order to obtain the necessary intensity of heat. This shows very clearly the principle involved in the construction of a furnace-hearth, and the boshes. Where the latter commence there the smelting of the ore begins, and not elsewhere. But as this rule would cause the crucible to be very high for refractory ores, it and the boshes form one general slope, which may be very high, as the ore requires no preparation in the upper parts of the furnace, and only the fuel is to be freed from moisture.

These principles are not confined to the kind of ore; fuel exerts more or less influence on the height as well as dimensions of a furnace. Hard, dry fuel, such as anthracite, requires little preparation in the furnace, and low stacks will work with it profitably. Coke requires more preparation, and charcoal most; and, as a high furnace has a tendency to draw the heat up, it is found necessary to reduce the height of a charcoal furnace in order to save fuel, by reducing the column of heat, and consequently radiation of heat. In the difference of the height of heat in furnaces, or in the radiation, which is the necessary consequence, may be found the chief cause of the great difference in the consumption of fuel. This accounts for the fact, that charcoal furnaces which smelt mild, fusible bog ores, will produce a ton of iron with less than a ton of coal, when anthracite furnaces use from 1·6 to 2 tons and more, and coke furnaces do not work with less than 2 tons of coke, which is equal to 3 or 4 tons of coal, for smelting the same amount of metal.

Hot-Blast.—The application of hot-blast at blast furnaces is general; with few exceptions at charcoal furnaces, it is done everywhere. In figs. 234 and 235, we have represented the apparatus, as it is most commonly constructed, which may be considered as its best form. In some instances the hot-blast stove is placed near the tuyeres, as shown in fig. 236; and each tuyere has its own stove, A A A, which enables the founder to heat the blast for one tuyere more than for the other, as its condition may require. At large furnaces, it frequently happens that one tuyere does not work so hot as the other, and in order to remedy the evil, more heat is applied at the cold one.

Fig. 234.

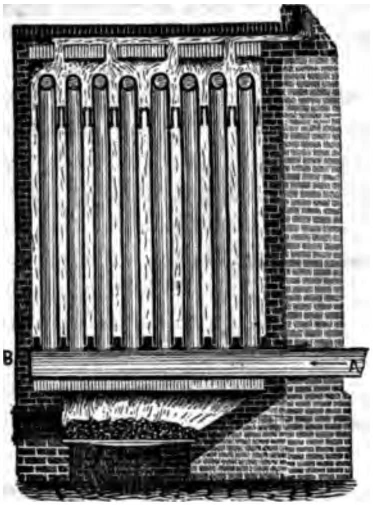


Fig. 235.

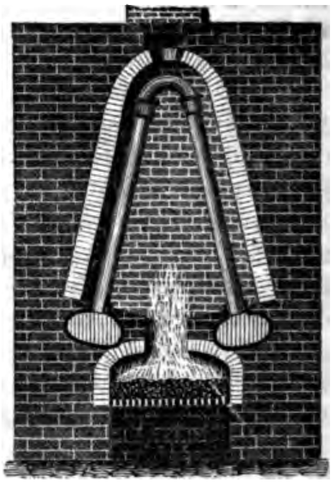
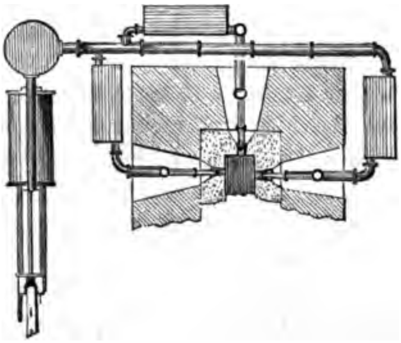
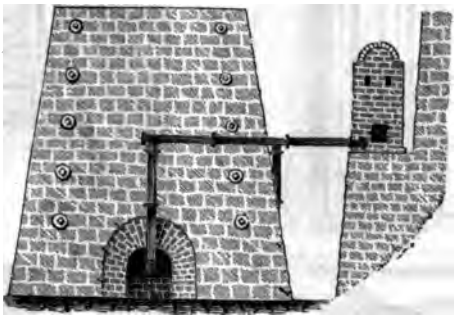


Fig. 236.



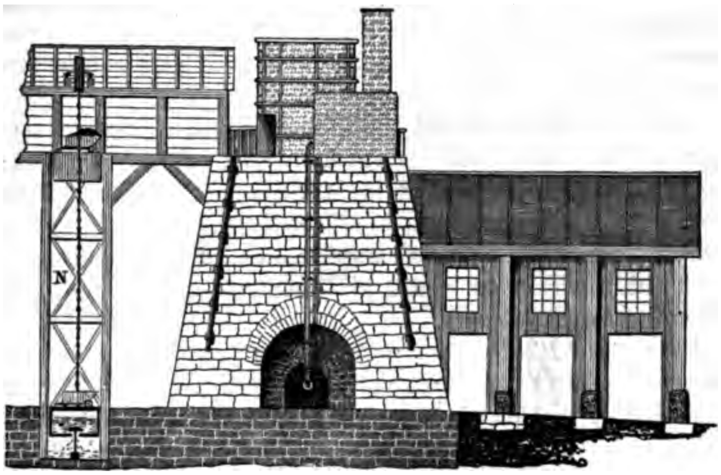
In general, one apparatus is placed conveniently near to all the tuyeres, and this heats the blast for all of them, howsoever many there may be. In this case the most convenient position is behind the furnace, somewhat elevated above the tuyeres, as shown in fig. 237. The hot-blast pipes are then above the heads of the workmen, and easily accessible for repairs.

Fig 237.



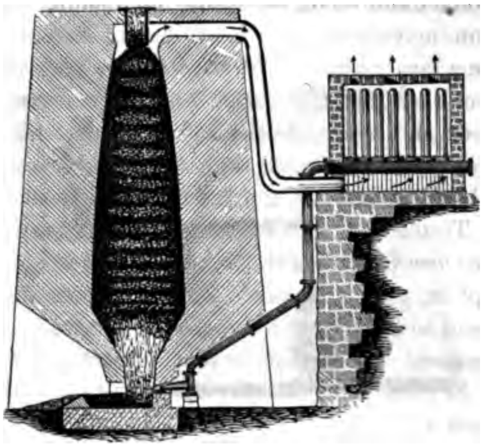
These cases refer to the method of heating the blast with separate fuel, which is not often practised. The most common mode

Fig. 238.



is to heat it at the top of the furnace, or at some distance below it, even as low as represented in the last engraving. The first instance has been represented in fig. 238; and in the latter, the arrangement takes the form shown in fig. 239. The waste heat is conducted from the top of the furnace, either in large iron pipes, or in channels of masonry, to that point where the hot-blast stove is located. In some instances, we find the stove provided with a furnace, or grate, for burning coal or wood. This precaution is taken to provide heat by extra fuel, in case the waste heat from the furnace is not sufficient to heat the blast to the degree required. This does not happen at anthracite or coke furnaces, but is confined to charcoal ovens.

Fig. 239.



At some furnaces we find the hot-air pipes inclosed in wrappings, which consist of articles which are bad conductors of heat; at others, the pipes are walled in, in the rough masonry of the stack. Whatever be the mode of conducting blast, the pipes ought to be spacious, for the increased volume of the hot air compared with it when cold, causes much loss of power, or pressure, if the pipes are too narrow.

Effect of Hot-Blast.—The apparently singular effect of hot air in a smelting-furnace, is chiefly of a chemical nature. The heat introduced by the hot air, amounts at best to $\frac{1}{6}$, and in most instances only to $\frac{1}{16}$ of that generated; and still a considerable amount of fuel is saved by it, which at charcoal furnaces amounts to $\frac{1}{4}$; at coke furnaces to $\frac{1}{3}$, and at anthracite furnaces to nearly $\frac{2}{3}$ of that used by cold blast. The immediate advantages are, the quantity of heat introduced, in case that is derived from waste-heat, a small increase of temperature, and a fluid cinder, by which flux is saved. The latter effect is in consequence of the absence of the chilling effect of cold air, and a more intimate union of the ingredients. The essential effect of hot-blast consists in its facilitating the union of carbon, and the oxygen of the blast, by which means carbonic oxide is more readily formed, in which gas carburetted iron may descend without loss of carbon. Cold-blast will produce a larger atmosphere of carbonic acid around the tuyere than hot-blast, and this gas will not only absorb carbon, but oxidize silicon and iron. As the influence of hot-blast on ore is of such a nature as to facilitate the revival of metals, many other substances besides iron ore are reduced, and form an alloy with the metal. To these foreign substances belong particularly those which are in close contact with the particles of iron, such as phosphorus, sulphur, and silex; calcium is often reduced from the limestone used as flux, when the blast is heated beyond a reasonable temperature. By experience it has been found that, for charcoal, a heat beyond 300°, for coke 400°, and for anthracite 500°, is of not much advantage.

The quality of iron smelted by hot-blast must naturally be inclined to gray iron, because all the oxygen and other gases being perfectly saturated with carbon, there is no opportunity for the ore to escape being carbonized. But it has been observed, and must naturally be expected, that hot-blast iron is more impure than cold-blast iron. It contains, particularly, more of the basis of silex, because this substance is every where associated with iron ore, and is subject to reduction by carbon at a high heat in the presence of iron, and in the absence of carbonic acid. The quality of the metal is, therefore, eminently suited for use in the foundry. It is, on account of the amount of its impurities, and the metallic form in which they are present, very fluid; and remains so a long time, which is the cause of its forming gray, tempered castings. Whatever may be the opinion and experience of some engineers, there cannot be any doubt that cold-blast iron with the same amount of carbon as hot-blast iron, and cast into dry moulds, is stronger than hot-blast iron, smelted from the same kind of ore. Hot-blast iron forms a superior foundry iron for small castings, but it is weak in large castings; the cause of which is obvious. The mixture of carbon, impurities, and iron, which causes its fluidity, makes it also a bad conductor of heat; it will not cool so quickly as strong and pure iron, and consequently, it is not so liable to crystallization. This iron may be, therefore, a superior foundry iron for small castings; but it must be always inferior to cold-blast for heavy ones, and particularly for the forge.

Waste Heat.—The large quantity of heat lost at the top of a blast furnace, has been the cause of frequent speculations to devise some plan for its use, since the earliest adoption of these furnaces. It has of late led to a great deal of controversy, and occasioned much examination of the nature of these gases, as well as of those in the interior of the furnace. The subject is so far settled at present, that it is found injurious to abstract gases lower down from the top, than where they consist chiefly of carbonic acid, vapors of water, a little carbonic oxide and nitrogen, and some other substances; in fact these gases are not abstracted until they cease to be useful in the furnace. We may tap gases from the furnace lower down in the stack, but they are not of more use than those near the top, and such an operation is more or less injurious to the working of the ores. When these gases are abstracted at a height where they cease to be useful we may term them waste heat; but if we tap lower down, they cease to be waste heat; for the highly carbonized, combustible gases are essential to the good effects of the furnace, as must be evident from our preceding remarks.

At a variable height, 8 feet on an average below the top in charcoal furnaces, 8 or 10 feet in anthracite furnaces, and 12 or 16 feet in coke furnaces, the gases are of the same, or similar composition. They consist here chiefly of carbonic acid, nitrogen and steam, and some carbonic oxide. It is a mere matter of convenience, so far as regards the furnace, at what precise spot we abstract the gas. Below these various heights it changes suddenly in its composition. It is composed chiefly of carbonic oxide, some hydrogen, nitrogen, and moisture. These are substances which are essential to the reduction of the ore, and which ought not to be removed.

We have already shown the mode of abstracting the waste heat from the furnace. The most common method is by means of a cast-iron cylinder of 5 to 8 feet in length, as shown in fig. 240, and in other drawings. The depth to which a cylinder is lowered has no effect upon the amount of heat obtained; this is regulated by the distance to which the heat is to be conducted. A long or deep cylinder affords more pressure, consequently the gas may be conducted farther from it. When steam-boilers, or a hot-blast stove, are at the top of a furnace, the insertion of a cylinder is not necessary, in fact it is of no advantage in any case, for sufficient heat is given out at the top in all instances, to heat steam boilers and hot-blast stoves. In this case the arrangement is such as is shown in fig. 241. A chimney at the end of the boilers, or at the top of the stove, produces the necessary draught. A plain cast-iron plate with a narrower mouth than that of the brick below, affords a chamber on the top of the fuel. When desired, this aperture in the iron plate may be covered by a door which is occasionally removed for charging fresh ore and

Fig. 240.

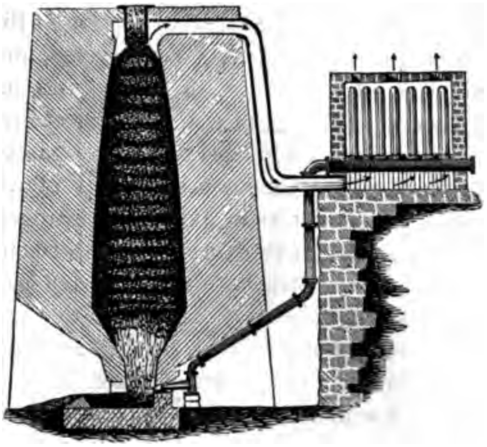
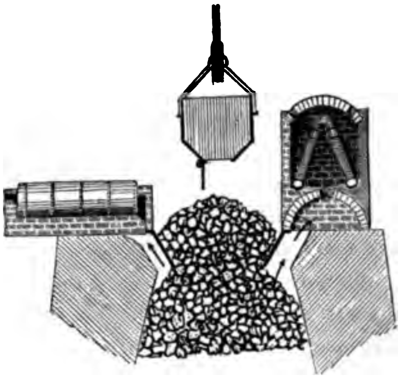
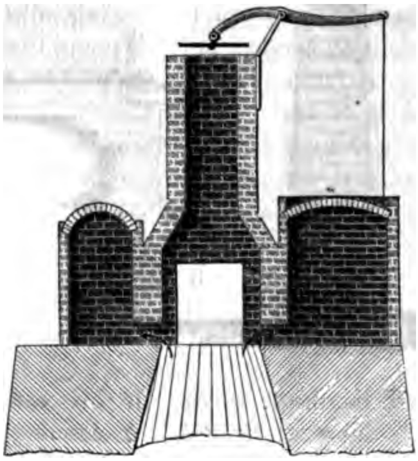


Fig. 241.



coal. This plan works well enough in small charcoal furnaces, but at large furnaces, with a wide mouth, and whose boilers require a large quantity of heat, the effects are not certain. If any objection exists to the application of an iron cylinder, which may be the case when the top works very hot, an arrangement such as is represented in fig. 242 is equally effective. It is particularly employed, and useful for burning lime, or heating blast. Over the mouth of the furnace a chimney is erected, provided with a damper on its top. Some iron doors, which are opened by pushing the wheelbarrow against them, and shut themselves when it is withdrawn, afford access to the interior for charging. By these means all the heat at the top is saved, and may be conducted to any place where it will be useful.

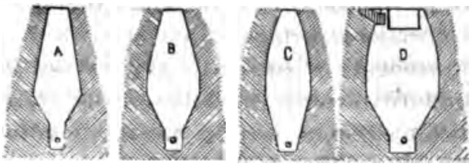
FIG. 242.



The amount of waste heat at a blast furnace is very large, but even when tapped low in the stack, and burned with the addition of fresh atmospheric air, its temperature is so low, that it cannot be employed to advantage for melting, puddling, or welding iron. At the top it produces a high red heat, and at anthracite or coke furnaces a white heat, well adapted for generating steam, heating blast, burning lime or bricks, and similar purposes. In conclusion, we insert some tables, which will be found useful for reference, explaining many things which could not be referred to in this short exposition.

Charcoal Furnace.—At a charcoal furnace the following persons are employed:—one founder, receiving $2 per day; two firemen, at $1 50 each; two fillers, at 75 cents each; one gutter-man, at $1; one coal-drawer, $1; a bank hand, and a horse, cart, and driver; and, if there is a stamping-mill, a hand to attend to it. This is the smallest number of hands necessary to manage a furnace; generally, there is twice that number. When ore is to be broken or roasted, flux to be broken, and similar work to be done, an additional number of hands is required. There are charcoal furnaces which consume 250 bushels of coal to a ton of iron; 200 bushels is an average in the Western States. In Western New-York, some furnaces smelt a ton of iron, from magnetic ore, to 150 bushels of coal; and in the St. Lawrence district, where specular ore and red hematites are chiefly smelted, as low as 100 bushels of coal are used to the ton of iron. A stack in that region, which operates well, is about 30 or 33 feet high; 7 or 8 feet boshes, with a cylindrical part, 2 feet high, above the boshes; mouth 31 inches, and from that to 36 inches (when an iron cylinder is used, it is of the same size); width of hearth between the tuyeres 22 inches, and 32 inches at the top; height of hearth, 5½ feet; tuyeres, 22 inches above the bottom; the in-wall a curve, as shown in fig. 243, C; such a furnace smelts from 5 to 8 tons a day.

FIG. 243.



The Siscoe furnace, on Lake Champlain, working magnetic ore, is 44·75 feet high; 13 feet boshes; 2 feet 10 inches hearth, across the tuyere; hearth, 38 inches high; slope of boshes, 64°, with a cylindrical part above the slope of 3½ feet high; mouth, 4 feet 3 inches wide. This furnace uses about 160 bushels of coal to a ton of iron; its erection has cost about $30,000, exclusive of 8 kilns for charring wood, which cost an additional sum of $10,000.

Anthracite Furnaces.—The form and dimensions of these vary exceedingly. They are not often above 33 feet high; from 10 to 18 feet boshes; 3½ feet to 5½ feet across the tuyeres; hearth, from 3 to 5 feet in height, generally much battered; boshes from 50° to 70°; top, 5 feet to 9 feet in width. A small anthracite furnace produces from 80 to 120 tons of iron, large furnaces from 180 to 200 tons, per week. The cost of erection of a small furnace is from $40,000 and upwards, large furnaces from $70,000 to $80,000, which use 1·6 to 2 tons of coal to 1 ton of iron.

Coke Furnaces.—These are generally 50 feet high, and as wide at the base; boshes, 15 feet; slope, 65° to 70°; hearth, across the tuyere, 4 feet; at top, 5 feet; height of hearth, 6 feet, and tuyere above bottom stone, 2 feet. The cost of erection is equal to that of an anthracite furnace; iron made per week, is 80 to 100 tons, using 2 tons of coke to 1 ton of iron.

The coal charges at furnaces are always of the same measure —about 15 bushels, more or less. The weight of ore is regulated according to the capacity of the coal for smelting. The number of charges in a certain time, say 12 hours, varies from 12 to 30, according to the quantity of blast injected into the furnace.

The number of blast furnaces in the United States may be estimated at 800; of which about 60 are anthracite furnaces, 8 bituminous coal furnaces, and a similar number which use coke. The others are charcoal furnaces.

Manufacture of Wrought-Iron.—Refining, forging, drawing,— these are the operations performed on crude iron, in order to convert it into wrought or bar iron. A great deal of wrought-iron is manufactured directly from the ore, of which we shall speak first. Before entering on this, we will, however, mention some of the general qualities of wrought-iron.

Qualities of Wrought-Iron.—We call wrought-iron that kind of iron which has received more or less labor when in a semi-fluid state, in contradistinction to malleable iron, which is annealed cast-iron, and partakes of the properties of wrought-iron. The difference in quality of the various kinds of wrought-iron, consists chiefly in the degree of malleability and ductility. We find wrought-iron as brittle as cast-iron and as malleable as copper, and as hard and brittle as glass and ductile as silver or gold.

The chemical composition of wrought-iron is, in some instances, similar to that of cast-iron, and it may be melted perfectly fluid, in a crucible, at a gentle heat. Good wrought-iron is nearly pure iron, with a mechanical admixture of cinder. It is infusible in the strongest heat of a coal-fire. In most kinds of commercial iron we find from $\frac{1}{4}$ to $\frac{1}{2}$ per cent. of carbon, also more or less sulphur, phosphorus, silicon or silex, manganese, and in all Swedish iron more or less arsenic.

The color of wrought-iron is from a dirty gray to a bright silver white, in the fresh fracture; the dark color is invariably caused by carbon. Pure iron is silver white, of little lustre, like deadened silver. When the lustre is high, or bright, and the iron shows an inclination to form crystals, it may contain silicon, which, however, cannot exist without the presence of carbon, and then the fracture of the iron is gray. Iron may contain phosphorus, or sulphur, or arsenic, without carbon. In these instances it may be perfectly bright, of a fine white color, and either brittle, cold-short, or fibrous. Other metals, such as manganese, chromium, and in fact all metals, are not often observed in wrought-iron. A high lustre in a fresh fracture is always indicative of the presence of some impurity, of which sulphur or carbon causes the least, and silicon, phosphorus, or arsenic, most. Tempered iron, when it contains carbon, is of a darker color than when hardened or chilled. The texture of wrought-iron may be fibrous, and the iron very impure; it may be short, and the iron very pure. When impure crude iron is puddled at a low heat, it may be very fibrous; but any heat, above that by which it has been puddled or welded, will convert it into brittle iron, similar to cast-iron. All fibrous iron is converted into crystallized iron, by tuyering or annealing it for a long time. All heavy wrought-iron is for these reasons not fibrous, and bars which are originally fibrous, but which have been exposed to a gentle heat, such as that of cinders in a furnace-stack, are invariably found to be crystallized in the fracture. The tenacity of such iron is dependent on, and in proportion to, its purity. This is not the case with fibrous iron, which may be very strong, resist strain to a high degree, and be very impure; in fact, we find that the purest kinds of iron are weak in these respects. Pure iron and carbon is the strongest of all compounds of iron, as shown in natural steel and in all kinds of good steel. A bar of steel, one inch square, will bear a strain of 150,000 pounds, before it is torn asunder; good Pennsylvania charcoal-iron will bear one of 130,000 pounds; puddled iron, from good Baltimore pig, 90,000 pounds; anthracite iron, puddled, from 50,000 to 70,000 pounds; and coke iron not more than from 40,000 to 60,000 pounds. These numbers depend in a great measure on the form of the iron, and it is not often that an inch-thick bar will bear so much weight. But, when iron is in small forms, such as wire, wire-rods, or hoops, the above numbers are nearly correct. Sheet-iron is the weakest form of malleable iron for resisting strain. The resistance to crushing depends on the hardness of iron. Pure iron, with carbon in chemical union, is the strongest, bearing a pressure of 210,000 pounds to the cubic inch; gray iron bears only 170,000 pounds, and wrought-iron 85,000 pounds; annealed iron far less than hardened iron, which is slightly tempered.

Test of Iron.—When we consider fibre a characteristic of wrought-iron, and insist on its presence,—which, in all cases where iron is subjected to direct strain, must be the first condition of its utility,—the most simple, and safest test is to heat the iron slowly to a high cherry-red heat, and plunge it suddenly into cold water. If, after this treatment, it retains its fibre, it is good iron. All iron, without exception, will crystallize on being thus chilled, when it is exposed to a white heat and then hardened; this test must be, therefore, limited to a certain degree of heat. It is merely indicative of the amount and nature of impurities, and the form in which they are present. Cast-steel is a very impure iron, and still is very strong when not heated to too high a degree; but, when we weld cast-steel, or expose it to a high heat, its strength is impaired, it ceases to be steel, and is merely good cast-iron, or wrought-iron,—we claim for wrought-iron welding properties at a high heat, and malleability after the application of such a heat. These properties accompany pure iron only, and increase with the degree of purity. Therefore, iron which is to bear a great deal of work, such as welding and hammering, which is exposed to strain and fibration, to constant motion or friction, to bending and re-bending,—such as wire-ropes, chain-cables, horse-shoes,—in fact, in all cases where iron is exposed to fibration, or work, or gentle heat, it should be of the purest kind; it will wear .only in proportion to its purity. Such iron may be at first less strong than impure, fibrous iron, but it will retain its strength, while impure iron soon loses its fibres when exposed to heat or fibration.

When we reflect on the nature of wrought-iron, we soon perceive the conditions under which it will be formed of good quality. Pure iron is extremely refractory, and we may reasonably doubt its fusibility by any temperature which we are able to produce by common means. Its great affinity for other matter, of which it is never free, causes it to be more or less fusible. It does not melt with oxidized matter. When brittle cast-iron is exposed to a gentle heat, imbedded in fire-proof oxidized matter,—such as oxide of iron, black manganese, sand, or coarsely-pounded clay, —it is converted into malleable iron; and if the crude iron does not contain too much carbon, or other impurities, the malleable iron thus obtained is very strong, and even ductile. It may be welded like wrought-iron. The cause of this is very plain. The foreign substances in the crude iron are oxidized in this operation, and the pores of the malleable iron are filled with oxidized substances, in case they are permanent,—such as silex, or lime,—or they are empty, in case the oxide of the foreign matter is volatile, as carbon, sulphur, phosphorus, or arsenic. The absence of crystals, or the reduction of the crystals to an extremely small size, is the cause of malleability.

The nature of wrought-iron is easily shown in examining the operation of puddling. Crude iron is fusible, and more or less so, according to the nature and amount of the impurities. In melting crude iron, in a puddling furnace, it comes in contact with cinder, containing much oxygen, namely, oxides of iron, manganese, &c. In mixing the fluid or semi-fluid iron with this cinder, it will assist and cause the oxidation of such substances as are more easily oxidized than iron, which of course diminishes the fusibility of the metal. The heat may be therefore raised on it, and when a certain amount of impurities is removed, it ceases to be fusible by it. Constant work, or mixing cinder with it, prevents the formation of large crystals, and the metal crystallizes, and adheres by cohesion, in small particles, forming a soft, spongy mass. The large pores in this mass are filled or covered with a coating of cinder, and, when compressed by squeezing or shingling, it forms an intensive mixture of iron and cinder. In drawing or stretching such a condensed mass—bloom—the crystals are elongated, form threads, and these, together with the oxidized matter which keeps them apart, form the fibre of the iron.

We thus see that fibre is the result of a particular form of metal, and may be produced with very impure iron, which, notwithstanding, may be very strong. If, for instance, these fibres of iron are similar in composition to strong steel, the iron must be of the greatest strength; and if they are of the composition of brittle cast-iron, the single fibres, and consequently the iron itself, must be less strong. Much depends, in respect to strength, on the fineness of the fibre; a coarse fibre will not cause such strong iron as a fine fibre. The durability of the fibres must necessarily depend on the purity of the metal, or, more correctly, on the degree of oxidation of the impurities. If carbon is present, or if sulphur, or phosphorus not oxidized, exists in the fine threads of iron, the exposure of it to such heat as causes the reduction of the oxidized matter,—cinder,—which forms the fibres by means of the inclosed carbon, must inevitably convert the fibrous iron into short iron, or, when very impure, into cast-iron. These reflections show at once the active cause in refining iron. It is the gradual oxidation and removal of its impurities, which, when performed under the influence of squeezing, hammering, and drawing, is much more perfect, because these operations force, by compression, the impurities from the pores of the metal. These introductory remarks, together with the principles involved in smelting, will enable us to understand the rationale of the following operations correctly.

The fusibility of wrought-iron is, as may be expected, extremely variable. It is stated to be between the melting heat of cast-iron and that of platinum, or from 2500° to 4000°. In this, together with its unsuitableness for conducting heat, is found its capacity of being welded. The degree of heat at which iron may be welded varies of course from a bright cherry-red heat to the highest white heat. The best indication of pure iron is, when it resists a high heat in welding, without losing its fibre. Some impure iron, in being heated to welding, will not bear the hammer,—it must be welded by squeezing it under strong pressure; this is impure iron made fibrous by work. Pure iron will bear any degree of heat, and any amount of work, without losing fibre. Impure iron may be welded with great facility, while pure iron requires not only a strong heat, but the absence of free oxygen in the fire. For these reasons, iron to be welded is covered with a coating of clay or sand, to protect it against the influence of free oxygen. Iron may be welded, because it assumes a pasty condition before it becomes fluid, by which its surface is more fluid than its interior. All pasty substances may be united in a similar manner.

The specific gravity of wrought-iron is from 7·2 to 7·9. No positive rule can be established by which to estimate the higher or lower point but that of actual weight. Pure iron may be light, or heavy, and such is the case with impure iron. Small iron, such as wire, sheets, hammered iron, is generally heavier than heavy bars, or rolled iron. The capacity of iron for conducting heat, electricity, magnetism, and other properties, does not come within the field of our investigations.

Wrought-iron directly from the Ore.—We shall not allude to those ancient methods of converting ore into malleable iron; they possess a mere historical interest. The present mode of operation is represented in the bloomery fires, as they are in use throughout the United States. A large quantity of iron is manufactured by them in the New England States, the State of New-York, Pennsylvania, New Jersey, Wisconsin, Michigan, and other States. This mode of manufacturing is confined to rich oxidized ores, such as magnetic ore, specular ore, crystallized red oxides, and some rich black or brown hematites. We may form some idea of the extent of these fires, when we consider that in the Northwestern part of the State of New-York there are 200 of them, which are, however, at the present time, not all in operation.

In order to abridge this subject, we represent in the following drawings the bloomery fire as it is most commonly used in New-York, near Lake Champlain.

Fig. 244.

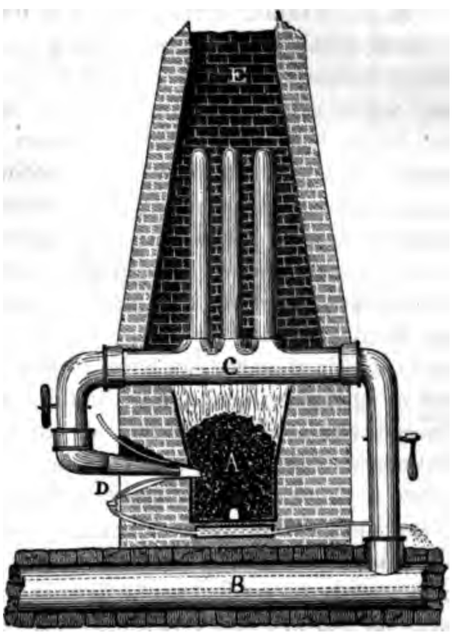


Fig. 244 shows a front elevation, and, partly, a section of a bloomery. A is the hearth, which is lined with iron plates; it is square, and generally from 27 by 30 inches to 28 by 32 inches. The height is from 20 to 25 inches above the tuyere, and from 8 to 11 inches below. B is the blast-pipe from the bellows, generally below ground; and C, a hot-air apparatus of the form represented in fig. 245. These pipes are so arranged that either hot or cold blast may be used. At D is a semicircular water tuyere. The water after being discharged here is conducted in a pipe under the iron bottom of the fire and confined in a separate box, from which it is finally removed to a drain below ground. Through the front plate is a hole, F, near the bottom of the fire; this serves for tapping off the cinder which may be superfluous. E is a chimney for leading off the waste heat, after having heated the blast-pipes.

Fig. 245.

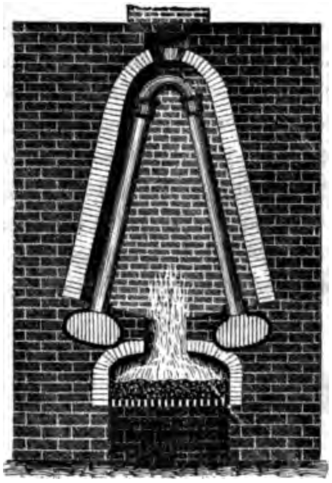


Fig. 246.

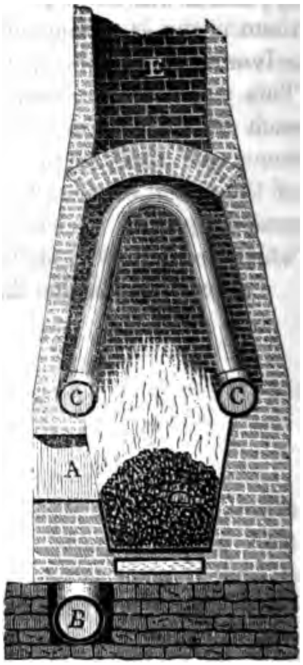


Fig. 247.

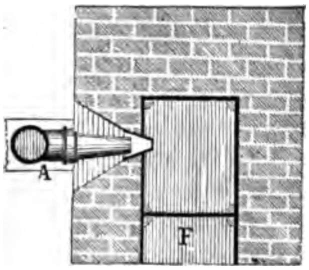
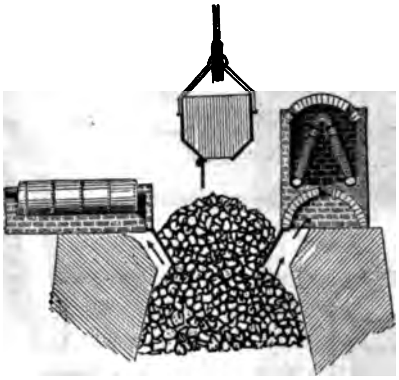


Fig. 246 represents a vertical section of the same fire in an opposite direction to that represented in fig. 248, in which the similar letters represent the same objects as above. We observe here, that the tuyere is not in the middle of the fire, but nearer the back of it. The cinder tap-hole, F, is also more distinct. Fig. 247 shows a horizontal section, through the fire and tuyere, which requires no particular description. Here we see the oblong form of the fire-box, and that the front of it, F, is only a simple cast-iron plate. Without further explanation the construction of this apparatus will be understood.

FIG. 248.



The mode of operation in these fires is very simple. The ore is broken, and pounded in stamping mills, converted into a coarse sand, and if impure washed to free it from impurities. Fire is kindled previously to throwing on ore, and when the hearth is thoroughly heated, the ore-sand is scattered over the top of the coal. A high heap of coal is kept constantly on the fire, and some ore in a body opposite the tuyere. The ore is thus heated, and in moving downwards towards the tuyere it is melted. The presence of hot carbon absorbs some of its oxygen and converts it partly into iron. This sinks to the bottom of the fire, and is there chilled. When sufficient ore is smelted to form a lupe, or bloom, no more is thrown on; the iron is raised from the bottom by means of a crowbar, brought into the heat before the tuyere, and when considered ready for the hammer, it is carried to it to be moulded into a square piece of iron, a bloom, of from 15 to 20 inches long, and 5 or 6 inches thick and square. When the iron thus withdrawn is shingled, fresh ore is thrown on the fire, and the process begins anew.

In some instances, these blooms are drawn out into flat or square bars, and in order to save time and heat, the waste heat of the two fires is concentrated into an oven, or stove, above the fire, as shown in fig. 249. Here we recognize the fire, from which the flame is conducted to the sand-hearth S, which heats the blooms, or bars, and is then conducted to heat the blast in the pipes, P. These pipes are straight and walled in the chimney. At O is a set of blast-pipes, more distinctly shown in fig. 250. These furnish heated atmospheric air to the waste heat from the fire, and burn any carbonic oxide which may happen to escape from the fires. In order to obtain sufficient heat for the stove, S, two fires are so located as to supply their waste heat to it. Or the fire works by two tuyeres, as shown in fig. 251.

Fig. 249.

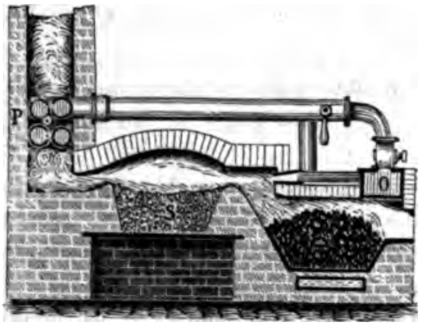


Fig. 250.

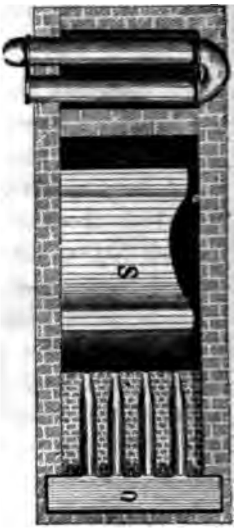
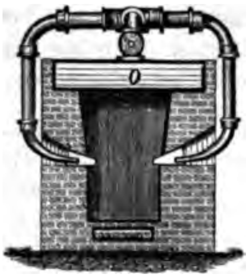


Fig. 251.



From these statements it is manifest that only a little capital is required to establish such forges; and where ore is cheap, they form the basis of a profitable business. As may be expected, pure specular ore is the most profitable in this case; it works quick and easy, and forms a strong fibrous iron, rather more so than magnetic ore. A great deal of the success depends on the purity of the ore; the quality and quantity of the iron are both determined chiefly by that. Clean ores, which at least furnish 65 per cent. of iron in the blast furnace, yield in this case about 40 per cent.; the yield of poorer ores diminishes rapidly. Ores of 30 per cent. of iron cannot be smelted at all; these form cinder only, or at best very little iron. By hot-blast, 2¼ to 2½ tons of ore are used, and 3 tons by cold-blast for a ton of blooms. For a ton of iron by hot-blast, 240 bushels of charcoal are consumed, and 300 bushels by cold-blast. The blast is heated in some instances as high as 600°. These fires work by a remarkably heavy pressure of blast, equal to that at blast furnaces. The wages for 1 ton of blooms amounts to $8, and an additional sum of $3 may be reckoned for blast, interest, repairs and superintendence. On an average, 100 pounds of iron are produced in 1 hour's time; in some instances there is more, amounting to 1500 pounds a day, or during 12 hours' work. Large fires make as much as 2000 pounds in that time.

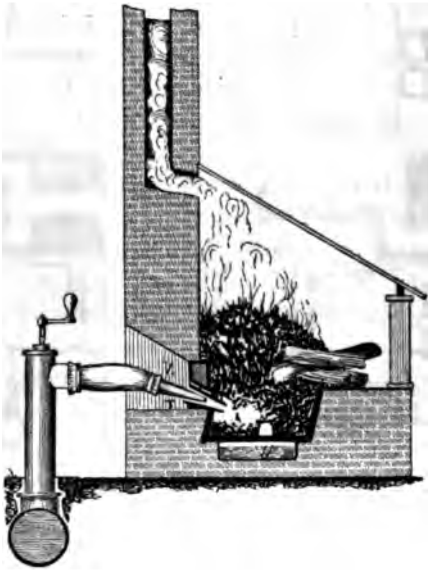
A large quantity of iron is manufactured in bloomery forges, of which those of New-York State are of such a capacity as to furnish 50,000 tons per annum. An equal amount may be expected from other States of the Union, so that the means for manufacturing blooms directly from the ore, are equal to 100,000 tons a year. The operation is not very economical; a great deal of stock is used for one ton of iron, and wages are not very low, so that a ton of hot-blast blooms cannot be furnished for less than $35. Puddled iron, which is in many respects superior to some kinds of hot-blast blooms, may be manufactured lower than these rates, particularly where mineral coal can be obtained at reasonable prices. These blooms form a superior iron for nail plates, and large quantities of it are converted into that article. It is generally purer than puddled iron, and very suitable for small iron. In heavy bars it is rather cold-short.

This mode of manufacturing wrought-iron is also called the Catalan method, which is conducted with the most ancient form of forges for making iron, and is still extensively practised in some parts of Europe. In those instances we find the fire, or hearth, formed of sandstones, and protected by heavy charcoal dust. Cast-iron linings are not often met with. By these means coal may be saved; but it causes a greater loss of ore than in our bloomery fires, and more labor. The form of fires described above, as used here, is the preferable one.

German Forge.—Gray or white pig-iron, is converted into blooms in bloomeries similar to those above described; they differ only in size and the mode of working. A difference in the size and form of the hearth, and its lining, position of the tuyere and manipulation, is made in the German forge in cases where gray pig-iron, white pig-iron, or plate-metal is worked. In most of these forges pig-iron is converted, and we shall therefore delay the description of the refinery, or run-out fire, until the close of this article.

In fig. 252, a vertical section of a German forge-fire is represented. The only difference between this fire and the above bloomery fire is, that the bottom is not so deep; it ranges from 6 to 10 inches below the tuyere, and the cast-iron linings are more or less inclined, which facilitates the operation and saves fuel. The tuyere T is, according to the kind and quality of crude iron, more or less inclined, and projects into the fire some inches. A water-tuyere, with solid bottom, is most generally used. The nozzle N, is made of light sheet-iron attached to a leather bag, and by that means to the blast-pipe, so as to be easily moved and directed to those parts in the fire where it works slow, and where blast is needed. Other parts of the apparatus are easily understood, and require no particular description. Fig. 253, shows a plan of the fire, two of which are frequently attached to to one chimney. Most modern fires have each a light chimney, constructed of bricks; it has no other office to perform than to

FIG. 252.



conduct the smoke and gases out of the building, and as the temperature in it is very low, it ought to be spacious—at least four square feet in area for each fire. An arrangement of fires, such as is shown in fig. 254, is more common than the one above.

FIG. 253.

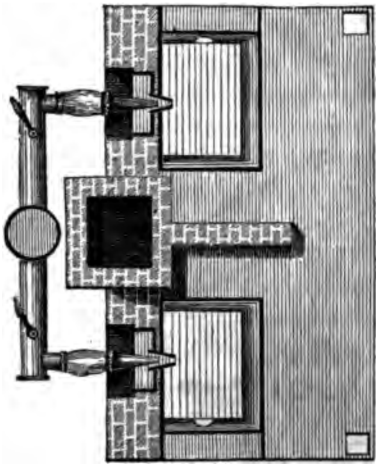
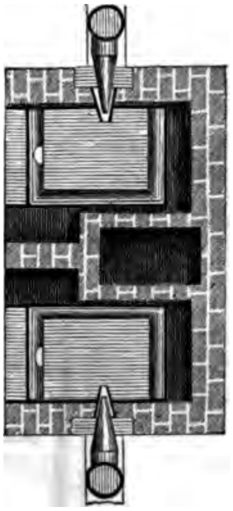


FIG. 254.

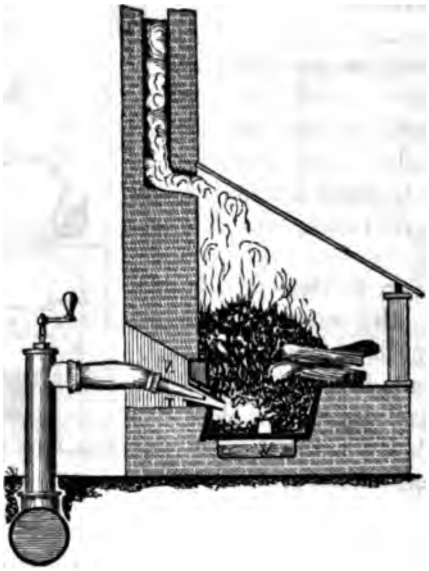


This plan is more compact, and occupies less space. The chimney C is then placed above the two fires, which are separated by a partition-wall.

The form of the hearth is the only important object in this apparatus; all the other parts may assume any form whatever, without any injury to the success of the operation. The blast should be dry, and from ½ to 1 pound of pressure is necessary; 150 to 300 cubic feet per minute, for each fire, are necessary to carry on the operation.

The form of the fire is an oblong, 24 × 26 inches, and from that to 25 × 32 inches, in the clear. The cast-iron linings are plates of 1½ to 1¾ inches in thickness, and firmly wedged together so as to resist the disturbance which may be caused by the use of the tools. The iron plate at the tuyere is inclined towards the fire, from 8° to 12°; the opposite plate is not quite as much inclined from it. Front and back plate are generally plumb; or inclined from the fire; the first is provided with a 2 inch circular hole near the bottom, for the discharge of slag. The bottom is formed of a cast-iron plate 2 inches in thickness, which is kept cool by the water box W, fig. 255. In some instances, the water is directed under this bottom plate, without the box, which causes the bottom frequently to break; the plan which is represented, is better on this account; besides, it does not cool the bottom quite so much as the direct application of water. The upper edge of the plates for the fire, and consequently the whole hearth, is from 15 to 18 inches above ground. The inclination of the tuyere, the inclination of its plates, and the slope of the bottom, are the most important subjects to be considered by the smith in constructing it. These are not the same in all instances. They are regulated by the quality of the crude iron, the iron to be manufactured, quality of coal, and the views of the workmen. Here, as well as in all other cases, the foundation of the hearth must be dry, so that no moisture may approach the fire.

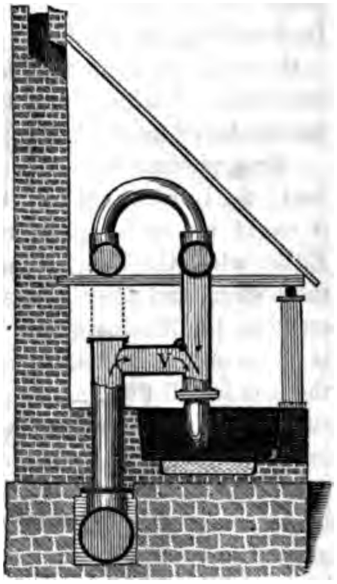
Fig. 255.



Hot-blast is not often applied in these cases; it is in fact of little service. A little coal, and a little iron may be saved; but quite as much is lost in the quality of iron as is gained in materials. And as charcoal iron is chiefly manufactured for the sake of obtaining good quality, there is little or no advantage in the application of hot-blast.

The hot-blast apparatus may be appended, as shown in figs. 244 and 249; or may be placed directly over the fire, as shown in fig. 256. And, as in this instance a high temperature of blast cannot be applied, the latter method may be preferable to the former, as it secures more durability to the apparatus. In all instances, the blast-pipes should be so constructed as to admit of a ready change from cold to hot-blast, and the reverse; for which purpose a valve, V, is appended, which admits of either hot or cold-blast, or both mixed.

Fig. 256.



The operation in these fires is very simple; with some experience, good iron may be made from any kind of crude iron. When the apparatus is well dried, by a slow fire, the hearth is filled with charcoal and a gentle blast applied so as to kindle all the coal and heat the plates, which are protected by a heavy layer of charcoal-dust. Hard charcoal, not of too large size—about that of an egg or a fist, is preferable to soft charcoal; it bears a stronger blast and works faster. Either previous to kindling fire, or when in blast, the bottom is covered by throwing on good rich slag, from previous refinings, namely, that obtained by reheating balls or blooms. A cover of at least two inches in thickness, should be on the bottom, and more than that when gray pig is melted. When the fire is thoroughly ignited, by applying about one-third of the full blast, or 150 cubic feet, blowing with a nozzle and tuyere of 1½ inches diameter, the pig-iron is charged, in the manner shown in fig. 211. From 200 to 300 pounds are charged at once, or gradually. When plate-iron is charged, the latter mode is applied; if gray pig, the former. But there is no rule for this; one refiner adopts one plan for all kinds of crude iron, others make a distinction. Gray iron requires less blast and less heat than white iron, a shallow hearth, and more dip of the tuyere; the bottom is also more inclined towards the front than when white or plate-iron is to be refined. A slope of 3° for the bottom may be considered the extreme adapted for very fusible iron. We must classify crude iron according to its fusibility, and not its color,—for impure white iron may work far slower than pure gray iron,—and when we here use the term gray iron, or white iron, we refer to the fusibility of the iron, not to its color. In describing the manipulation, we will treat of the two extremes, —the working of gray iron and of plate-iron. The bulk of crude iron used, and which forms the varieties, is worked between these two modes of manipulation.

Gray pig-iron is melted in at once, by applying a very low heat; the broken pigs may therefore be placed above the tuyere; it ought not to be quite fluid when it arrives at the bottom. Either while the iron is thus melting down, or when it is all at the bottom, and after it has been gently stirred by means of a crowbar, the floating cinder is tapped off and thrown away. It is of no use, and contains most of the injurious impurities. If the iron is still fluid, some hammer-scales are thrown on it, and a stronger blast directed upon it; it is then stirred, and the resulting cinder is tapped and thrown away. When thus made more coherent, the iron is broken up, lifted from the bottom, and heated in parcels before the tuyere. The still crude iron now melts again, and on arriving at the bottom begins to boil. If it is now diligently stirred, by means of an iron bar, under an increase of blast, it gradually gathers into lumps; when, in this condition, the cinder is again tapped off from the iron and saved. The mass is now tough, and assumes the nature of wrought-iron. Under an increase of blast, this iron is turned about, thoroughly heated on all sides, and gradually converted into one or more round balls, which are now brought to the tilt-hammer and shingled down into blooms. All this time the fire is well supplied with coal, and the blast increased to its full force on the finished loop. If the iron is very impure and fusible, it will require a great deal of labor and the use of much coal; still, the yield cannot be expected to be high, particularly when a good quality of iron is to be made. As much as 250 bushels of coal may be consumed on weak pig-iron; 4 hours' work is required on a heat, and 30 per cent. of iron may be lost.

White iron, or plate-iron, is worked on a different plan. The basin of the hearth is deeper than for gray iron, the tuyere does not dip so much, the blast is stronger from the beginning, and the work commences as soon as melted iron arrives at the bottom.

This kind of iron is never very fusible, and if it is fluid, it does not long remain so after being exposed to the effect of the blast. The purer and stronger the iron is, the more it is inclined to coagulate. So soon as it is partly melted, it is lifted from the bottom, brought before the tuyere, and by turning it about it is heated and refined on all sides. Those parts which do not resist the strong fire, melt down again and are taken up a second time. A number of small balls are thus formed, which, on being exposed to an increasing heat, are welded together and formed into a large ball, of 100 or more pounds, which is brought under the hammer for compression. The work on this kind of iron proceeds faster than with gray iron, less coal is used, and the yield is far better. In two hours 300 pounds can be heated, and a ton of iron by the use of 120 bushels of charcoal, and from 85 to 90 per cent. of iron yielded from the crude plate-iron. One fire will easily produce from 4 to 5 tons a week, while from gray pig-iron not more than half that quantity can be obtained.

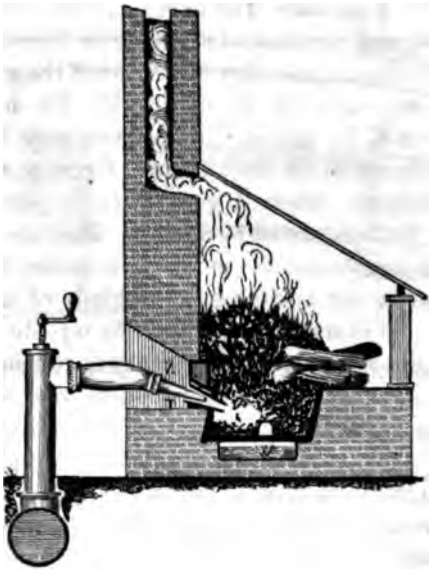
The methods of making wrought-iron by these means are innumerable, but the variations are chiefly caused by the quality of the crude metal and the quality of iron to be produced. An important point, relating to the success of our forges, is the quality of the iron manufactured; for their success, in fact their existence, depends upon good quality. Puddled iron can be manufactured much cheaper, and supplies the market with inferior qualities at prices at which charcoal-iron cannot be made. To produce good charcoal-iron, such as is equal to the Swedish article, requires good cold-blast pig-iron. All experience has shown, and theory confirms it, that first-rate, pure and uniform iron, cannot be manufactured directly from the ore, nor from hot-blast iron, in competition with the foreign article,—at least, not at prices which are offered at present. The iron most in demand, and for which reasonable prices are obtained, is wire-iron, steel-iron, and iron for the use of hardware manufacturers of fine articles. Iron for these purposes must be very pure. It is of little or no consequence if such iron is fibrous, or not; on the contrary, for most of the above-named articles, the granulated iron is preferable. Iron of high purity cannot be manufactured of white plate-iron, neither can it be made of hot-blast iron, or directly from ore, no matter how pure the minerals and the fuel are. Mottled pig-iron, smelted of good ore with good charcoal, in a low hearth and steep boshes, is the only form which will produce bar-iron, fit for prime qualities of steel and other similar uses. When such mottled iron is melted in small quantities, of not more than 80 or 100 pounds at a time, in the common German forge, and boiled, there is not the slightest difficulty in making first-rate iron. When hot-blast is avoided, and no cinder or hammer-slag from any inferior quality of iron is used, great cleanliness observed about the fire, and diligence displayed on the part of the workmen, we cannot anticipate any difficulty. In this operation, much coal, labor and iron are consumed,—and in some instances they may twice exceed what is required for common iron,—but the price obtained for good iron compensates for the higher cost. It is impossible to make very pure iron without these means. Innumerable experiments have been tried to manufacture it with the assistance of artificial fluxes, with but little success. The form and nature of iron requires the use of very good fluxes, such as iron itself, manganese, and potassium or soda. All attempts to employ the latter successfully have failed, and no other fluxes can be used to advantage than those which the crude iron contains. For this reason, iron smelted by charcoal, and from ore which contains manganese, furnishes always strong, and in most instances the purest kinds. But it is an essential condition that such ore should be smelted by charcoal and cold blast, or the presence of manganese ceases to be advantageous.

Steel.—This is, and may be, manufactured from any kind of good gray pig-iron, or white plate-iron, smelted from sparry ore. No other alterations at the fire are required, than to do away with the cast-iron lining, and bottom and surround the fire with argillaceous sandstone. The bottom ought to be formed of a very strong, well-dried sandstone, or it does not last long; and a good one does not often last longer than 7 or 8 heats. In this instance, the fire is somewhat more contracted in size than that for iron; the tuyere higher, about 10 or 11 inches above the bottom, and not much inclined, so that the blast does not touch the iron on the bottom. A strong blast and little work; melting off the tuyere in small quantities of from 25 to 40 pounds; and melt no second piece until the first is hardened in the bottom,—these are the rules to be observed. The quality of steel depends entirely on the quality of the crude iron, and on the skill of the steel-maker; but chiefly on the first. An impure iron never will produce steel; and all attempts to make a useful strong article from poor ores, weak iron, or coke or anthracite iron, will prove unsuccessful. This mode of making steel, generally known as the German method, is not proper to be employed in this country, and is not in use. It requires a kind of crude iron expressly smelted for the purpose, causes much labor and the use of much charcoal. The steel thus made is generally a mixture of iron and steel. There is much labor and loss of metal in refining, and tediousness in assorting, which cause it to be an expensive article. Welding steel, shear-steel, or German steel, may be made of blistered or cast-steel, in greater perfection and at less expense than that directly from the crude iron. Of this we shall speak at the close of this article.

Refining of Crude Iron.—A variety of means may serve for refining crude iron. Little use is made of refining in our iron-works, and therefore we shall not spend much time on this subject. It is an important part of the description of the manufacture of iron, as it supplies the means for a philosophical examination of crude iron. Any re-smelting of a fusible metal, and therefore of iron, is to a certain degree a refining operation. In many instances it is performed for the express purpose of improving the quality of the metal; in others, that improvement is incident, and the fluid metal the object. The re-melting of iron in a cupel oven includes the refining of the metal; when this is performed with the addition of suitable fluxes, we perceive a remarkable improvement in the quality. Melting in a cupel oven by charcoal has a superior effect to that by anthracite, which furnishes a more purified iron than the melting by coke. In melting iron for the foundry, it is the object to retain as much carbon in it as possible. This ought to be the object in refining for the forge; the separation of other impurities is then possible, but not so without the presence of carbon. The practical difficulty of purifying iron in the puddling furnace and the forge fire, consists chiefly in the cold surrounding walls of the fire, which are most commonly of iron plates. This causes the crystallization of many particles of iron which are not sufficiently purified, and consequently defeats the object of the process. In order to retain the fluidity of iron, and at the same time remove those impurities which are injurious to its quality, the presence of carbon and hot walls of the furnace are required. These statements are the result of repeated experiments in refining iron in the cupel oven, on our own part, which led to unexpected results. Having been engaged in improving iron, by means of artificial fluxes, for many years, and having met with many defeats, we were naturally led to reflect on the cause of these failures, and came to the conclusion expressed above, and in consequence of cupel oven experiments. The result of these experiments is, that any inferior crude coke or anthracite iron is not improved in re-melting it in a cupel oven with fluxes which may part with oxygen, such as the oxides of iron, or oxides of other metals. The alkalies and their salts are likewise of little use,—they evaporate entirely at the high heat required for re-melting iron. The only practicable flux was found to be limestones, and the best is argillaceous limestone. Quicklime had little influence, and this forms one of the strongest arguments against its use in the blast furnace. By means of good limestone, any iron, no matter how impure, may be improved, provided the limestone is fusible, and forms a slag before it arrives at the tuyere; when it goes down in pieces which are not melted, but little is gained in quality. This mode of refining, however safe, is not practicable in most instances, for it requires so much limestone for purifying some kinds of iron, that the quantity used is an obstacle to success. By repeatedly re-melting iron with less limestone, a good result may be obtained. In order to avoid or remedy this evil of too much limestone, we have had a limestone furnace constructed, so that with the addition of a limited amount, the iron might be deprived of its impurities. This operated well enough for melting a few tons of iron, when the limestone walls were eaten away, and it became necessary to renew them. By these means iron well purified for the forge-fire or the puddling-furnace may be obtained, but the operation is expensive, because of repeated re-melting, or interruption caused by repairs. The loss in iron is very small, and the use of fuel no serious objection to this mode of refining. We may inquire, why here, as any where, carbonate of lime has so beneficial an influence on crude iron. The cause may be found in the nature of the most injurious impurities of crude iron, and the nature of the iron itself. The substances which chiefly accompany crude iron, are carbon, silicon, phosphorus and sulphur; lime combines with all of them, except carbon. Phosphorus and sulphur may be effectually removed by quicklime, and equally as well by carbonate of lime; the carbonic acid and oxygen is readily driven off by these substances. Silicon does not combine with lime; it may in part, but when it absorbs oxygen from quicklime, it will form a large quantity of calcium, which is equally, if not more, injurious to iron than silicon. Carbonic acid is here decomposed by silicon, and the latter forms, by being oxidized, a silicate of lime. By these means carbon is retained in the iron, while most of the other impurities are removed. We shall now be enabled to appreciate the value of the following modes of refining.

A bloomery fire, or a German forge, fig. 257, is a suitable refinery. Merely melting the iron in this fire, tapping it at the tap-hole in front, and running it into chills, furnishes an improved crude iron. In this operation fusible limestone may be used to advantage; an addition of 10 per cent. of such limestone will effectually remove 3 or 4 per cent. of phosphorus. A second melting with the same quantity of limestone will produce a perfectly pure and strong iron. This mode of refining is expensive, on account of the large quantity of coal used, and the small quantity of iron furnished from the crude-iron. It is not often attempted.

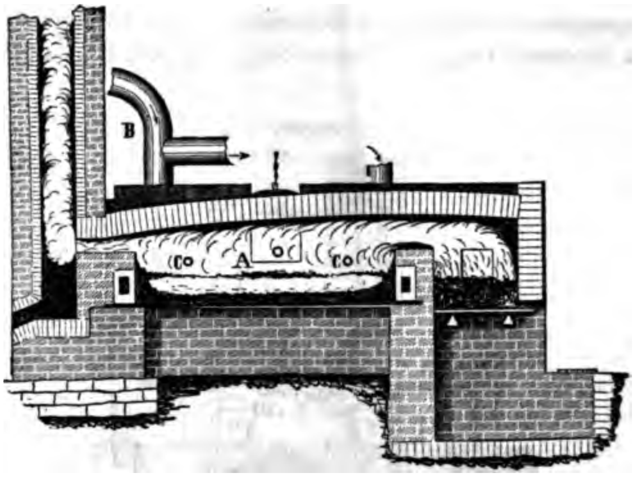
Fig. 257.



Some years ago, a reverberatory furnace was recommended, and employed for refining crude-iron. We are not aware of its use at the present time, but as we shall have occasion to refer to it again, we furnish an illustration of such an apparatus in fig.

258. The furnace, as represented, has the form of a common reverberatory; the hearth A, is from 7 to 8 feet long, and 5 or 6 feet in the clear. The fire-grate is supplied either by blast, or draught. A ton of iron is charged at once in the hearth, with fluxes of lime or hammer-slag, oyster shells, or forge cinder, and melted with them. When perfectly fluid, various currents of blast, supplied by the pipes B, and tuyeres C C, in the opposite sides are directed on its surface, which oxidize iron and impurities, and by these means produce plate-iron of more or less good quality.

Fig. 258.



We suppose, there is no necessity of explaining why this mode of refining cannot produce satisfactory results. Good iron may thus be made from good pig, and also phosphorus and sulphur may be removed; but the greatest obstacle, namely, silicon, cannot be got rid of by these means. There is too much free oxygen for the effectual removal of it, the iron is deprived of fluidity before the newly formed silica can be expelled.

In fig. 259 we represent a vertical section of a run-out fire. This is an iron frame-work about 4 feet square, and 8 feet high, surmounted by a brick, or sheet-iron chimney. These fires are worked by two rows of tuyeres, one opposite to the other. Those fires with but one row, are not much in use, and are smaller. The tuyeres A A, are about 9 or 10 inches above the bottom, which is formed of a sandstone slab, or of fire-bricks, or of coarse sand. The cast-iron sides of the furnace, B B, are hollow, and supplied with a permanent current of cold water, so as to keep them cool. The tuyeres are also water-tuyeres, supplied from troughs above. The water from the tuyeres and the boshes is conducted into an iron trough, which surrounds the furnace, so as to prevent its penetrating below the hearth. In fig. 260 a plan of the fire is shown. We see the disposition of the 6 tuyeres A A A, at some fires there are only 4, and at single fires but 2. We also see the arrangement of the blast-pipes; the chests C C, serve for the proper adjustment of the nozzles. The quantity of blast is regulated by a trundle-valve in the blast-pipe, or by a dish-valve in the chest. In this engraving we also observe the arrangement of the water-boshes; the tap-hole D, in front, and the chill, or mould, into which the iron is cast. This latter is more distinctly shown in fig. 261,

Fig. 259.

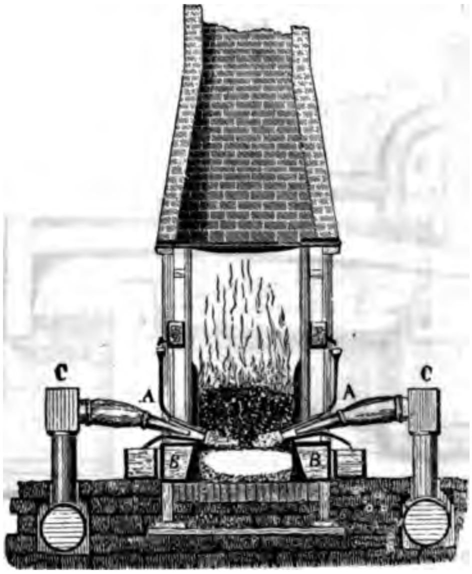
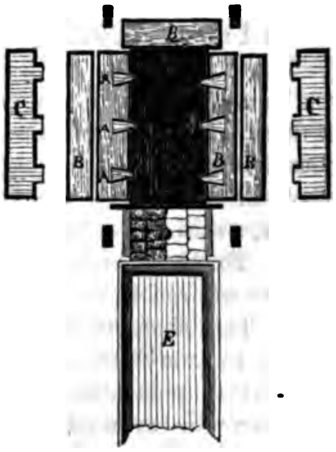
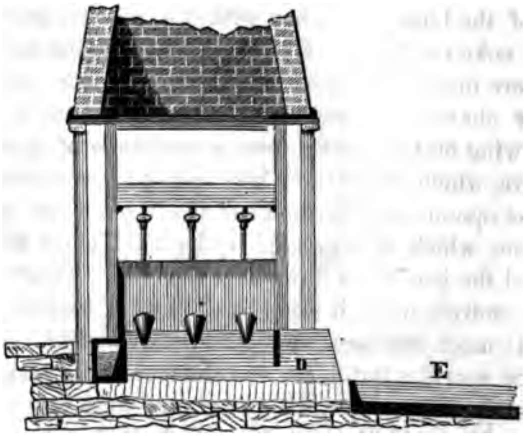


Fig. 260.



which is a vertical section in an opposite direction to that of the first engraving. The back of the fire, as well as its sides and front, are in some instances closed by sheet-iron doors, to protect the workmen. The chill, or mould E, is a heavy trough of cast-iron; it should be at least as heavy as the iron cast into it, or heavier, which is better still. It is from 10 to 16 feet long, and 22 to 28 or 30 inches wide, according to the quantity of iron melted at once. The sole or bottom of the hearth, when made of coarse sand or fine gravel, is liable to be filled with iron, and should be broken up every week and replaced by a new bottom.

FIG. 261.



The manipulation at these fires is very simple; either charcoal or coke, chiefly the latter, is used as fuel. When the hearth is filled with coal, and this is thoroughly ignited, 500 or 600 pounds of pig iron are charged on the top of it at once. The whole of this iron is again covered by fuel. When it begins to melt, a second charge, of an equal weight with the first, is applied. To this fuel is added, and the filling is continued until the quantity of iron is sufficient to cover the bottom 5 or 6 inches deep. This amounts in small fires to about ½ a ton, and in large ones to 1½ tons of iron. The charging of iron now ceases, and only fuel is supplied, which is always kept at least 12 or 24 inches high above the tuyere. In a fire with 6 tuyeres, and strong blast, 1½ tons are melted down in one hour, and if good pigs have been smelted, ½ an hour more will finish the heat; thus a heat may be made in 1½ hours' time. Gray iron and inferior iron, consume from 2 to 3 hours for one heat. In Pittsburgh, where charcoal pigs chiefly are used, a fire refines about 8 tons in 12 hours. Of coke pig, or anthracite pig, less can be refined in the same time. The blast for coke must be strong; when playing on the surface of the melted iron, it generally keeps the coke suspended, so that it hardly touches the iron, and as this is necessary for success, the pressure of the blast must vary with the specific gravity of the fuel. For coke the density of blast is about 1 pound to 1½ pounds to the square inch. The blast is generated in iron cylinder bellows. For charcoal ½ pound to ¾ pound pressure is sufficient. While blowing on the melted iron, a multitude of sparks escape from the fire, which are burning iron; when these sparks are very profuse, the operation is finished and the iron let out, or run out. The tap-hole, which is stoppered up by sand, is for this purpose opened, and the iron flows down into the chill. When too many sparks are emitted while it flows, and the iron looks mushy, it is too refined; much has been, and will still be wasted. When the flowing iron sparkles but little, and the iron flows very thin, it is not sufficiently refined, and will cause slow work in puddling.

The mould, or chill, is coated with a clay wash, which prevents the adhesion of the fine metal to the chill. This coating must be perfectly dry, and in fact the whole of the mould must be free from any moisture, or dangerous explosions may happen. A portion of the slag, which follows the iron from the fire, remains on its surface, and forms a crust which flies off as the metal gradually cools. When it is so far cooled as to be hard on the surface, a stream of cold water is conducted over it, which causes it to crystallize, whitens the metal, renders it brittle, and more suitable for subsequent operations. The plate of fine metal, which is from 3 to 4 inches thick, is broken up and removed to the puddling furnaces. The waste of metal in this operation is from 8 to 25 per cent.; good charcoal iron loses the first, and bad coke iron the latter amount. For refining one ton of fine metal, 500 pounds of coke or 30 bushels of charcoal are used.

In this process, as well as in the bloomery fire, no artificial fluxes have been employed with success; the only substances which are sometimes used are limestone, or forge cinder. The color and other appearances of the fine iron are no indications of quality; nothing but actual trial by puddling can decide on its value. From the nature of the operation it may be inferred that carbon chiefly is removed, and that silicon and other substances remain in the fine iron. This is proved by practice; for very impure iron, which causes much waste in refining, is not much better after that operation. Gray iron of good quality is improved to some degree, but not sufficiently to pay for the trouble.

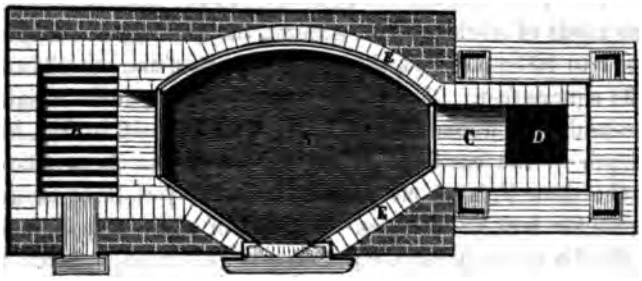
When we take a critical review of this operation of refining, we find that it is of little service in the manufacture of iron, and are much gratified to perceive the gradual disappearance of this superfluous addition to the iron works. There is not the slightest difficulty in producing good iron in the forge or puddling furnace, without refining. And if we are inclined to spend much labor and fuel, we may succeed in forming a better article without, than with the assistance of the finery. The leading principle in this operation is, or ought to be, economy; a saving of crude iron from the pigs to the rough puddled bar. But if we examine this subject, we find that nothing is saved by refining. Taking the loss in the finery together with that of the puddling furnace, it exceeds always the loss of iron where it is puddled in one operation directly from the pigs. The latter process causes about 25 per cent. more labor without, than with refining; which is compensated by the expenditure in fuel and labor at the finery.

Forge cinder, from the very best iron, consists of about 93 protoxide of iron, or alkalies, and 7 silex, in 100 parts; while that from ordinary charcoal forge iron consists of about 80 alkali and 20 silex; and puddling cinder from 60 oxide of iron and 40 silica to 70 iron and 30 silica. The cinder from a finery is composed of from 60 oxide of iron and 40 silica, to 70 alkali and 30 acid. We omit to furnish exact analyses, which include alumina, phosphoric acid, and other substances, because these, in fact, have nothing to do with the point under consideration. If in a finery a cinder could be formed which consisted chiefly of other alkaline matter, containing little or no iron; and if such a cinder could not be produced in a puddling furnace, there would be some reason for applying a separate process for refining crude iron. Blast furnace cinder from good charcoal blast-furnaces, consists generally of a number of elements, such as the following, from a Swedish blast furnace. Silica 61·06, Alumina 5·38, Peroxide of Iron 3·29, Peroxide of Manganese 2·63, Magnesia 7·12, and Lime 19·81. If a cinder of a similar constitution could be formed at a finery, there is no doubt advantages could be derived from it, but not otherwise. So long as the cinder in the puddling furnace does not contain much more iron than the finery cinder, there is little advantage in refining. But when the object is to make a very pure iron in the forge fire, or a pure fibrous iron in the puddling furnaces, in which case a slag of some 70 or 80 per cent. of iron is formed, and used in the finery as flux, there may be advantages in refining. This case does not happen, because the iron obtained by such an operation would be too expensive.

Puddling.—This part, or branch, of the iron business has been much cultivated of late years, and is still undergoing daily improvements. We shall confine our remarks to the most common form of furnaces, and mention such alterations as are incidental to particular localities and material as we proceed. Puddling is the most rational process of refining iron, and must finally supersede all others. That it has not done so already, must be ascribed to some practical difficulties which we shall mention presently. Personally, we have had much experience in this branch, meeting often with good success, but more frequently with disappointment.

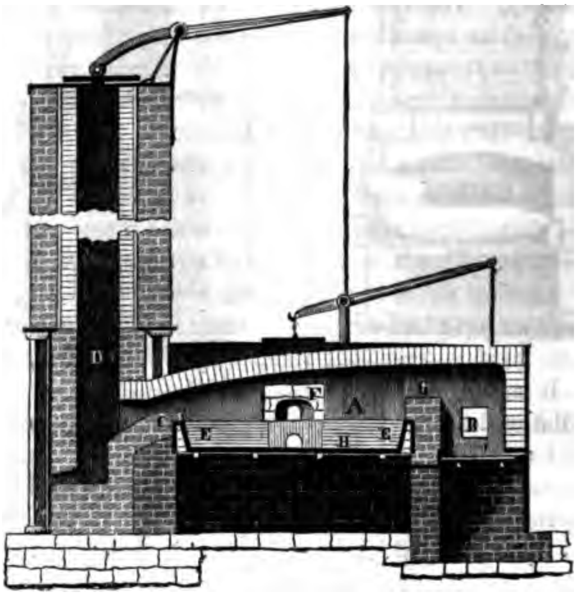
Single Furnace.—The form of apparatus in which puddling is performed may be divided into two classes, single furnaces and double furnaces. The manipulation itself is also divided into two classes, termed puddling and boiling. A single furnace is represented in fig. 262, of which A is the hearth on which the operation of converting cast-iron into wrought-iron is performed. B is the furnace or fire-place; C, the flue leading to the chimney D. All the interior parts are constructed of good fire-brick, and the whole is inclosed by a casing of cast-iron plates. Around the hearth A, runs a double lining of cast-iron, called the boshes, marked E. These are more distinctly shown in fig. 263, which is a vertical section, through the grate, hearth, and stack. The cast-iron boshes, which are open below, as shown, are prevented

FIG. 262.



from melting by a circulation of air, which has access from below the bottom. The whole length of the furnace is about 12 feet, and that of the stack 4½ feet. The dimensions of the parts in this furnace vary in some measure according to the kind of iron, coal, and the mode of working. In general, the grate affords a surface of from 7 to 10 square feet, the working part of the hearth is from 16 to 24 square feet. The depth of the fireplace, or the height of the fire-bridge A, above the grate bars, is from 18 to 22 inches. The depth of the cast-iron bottom-plate H, from the work-plate below the door F, is about 6 or 7 inches for puddling, or 10 to 12 inches for boiling furnaces. The width of the flue C, is such as to afford a sectional area, equal to ⅕ of the grate-surface. The interior of the chimney is about 18 or 20 inches square; and so high as to reach over the roof of the building.

Fig. 263.



In the drawing, fig. 264, we represent a vertical section, across the work-door. It shows the position of that door, and the form of the roof. In fig. 265, a section across the grate and the stoke-hole is represented. The latter is filled with coal, instead of being shut by a door. This mode of shutting the fireplace is applicable when the furnace is worked by draught only. When blast is applied below the grate an iron door is made. As remarked before, the whole of the furnace is surrounded by an iron inclosure, which is most generally formed of cast-iron plates, screwed together. It may be formed of loose cast-iron plates, or of rough bars, or flat mill-bars equally as well, as we shall show hereafter.

Fig. 264.

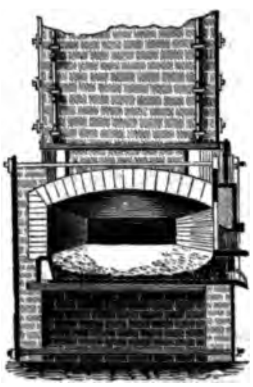


Fig. 265.

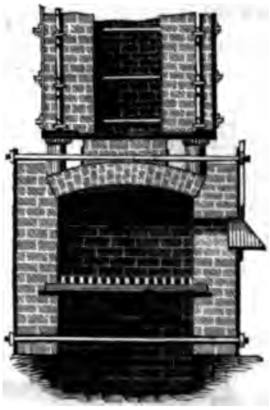
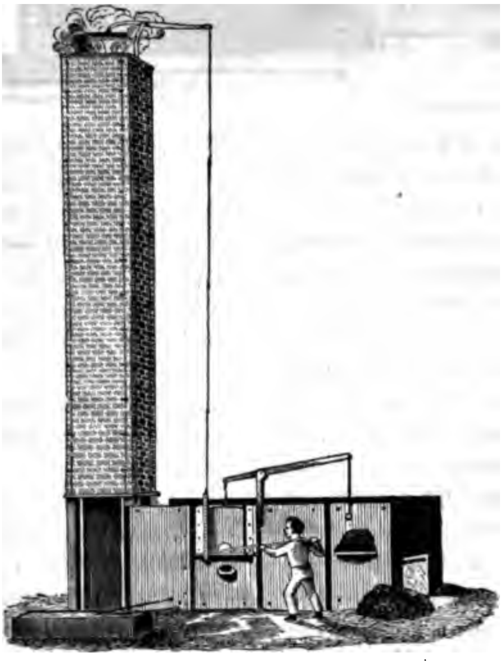


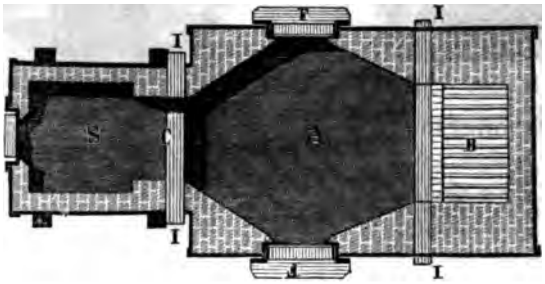
Fig. 266.



In fig. 266 the whole of a furnace is represented in view, as it is commonly constructed, and in use in the Western States, particularly in the Pittsburgh coal region. The inclosing plates are about $\frac{3}{4}$ of an inch thick, and their strength depends chiefly on the ribs by which they are screwed together. The brick chimney, which is lined with firebrick, rests upon 4 strong cast-iron columns about 5 feet high. That part between these columns, is also inclosed by iron plates, and is formed entirely of firebrick; it is exposed to the highest heat and needs frequent repairs. The above is the most simple form of a puddling furnace.

Double Furnace.—Throughout the States, on the eastern slope of the Alleghanies, we do not find many single puddling furnaces in operation; most of them are double furnaces with opposite doors. Fig. 267 shows the ground plan of the hearth, grate, and flue, or stove of a double furnace. The work-doors F F, are here opposite each other, so that two men may be at work at the same time. The general dimensions of this furnace are not much larger than those of a single furnace, and if any advantage exists in the single furnace over the double one, which is frequently asserted, it is in the comparatively larger dimensions of the hearth, which admits of the presence of more cinder in proportion to the iron worked at a time; and also the absence of the second door, in consequence of which the hearth is not so much cooled by the entrance of cold air. In general, the advantages of the double furnace so far predominate, as to cause the gradual disappearance of single ones. The surface of the grate is here not often less than 15 square feet; the area of the hearth about 40 square feet, and the area of a section of the flue, 2 square feet. The total length of the furnace, exclusive of stack, 12 or 13 feet, and the width outside 6½, and from that to 7½ feet. Behind the flue, in the prolongation of it, there is a stove S, for warming pigs, which is more distinctly shown in fig. 268. In some furnaces, we find simply

FIG. 267.



square cast-iron pipes of about 6 inches in width, I I I I, laid across the furnace, forming the fire and flue bridges; these pipes project through the inclosure. By these means the baking of cinder through the bridges is prevented. In this instance, the hearth of the furnace is lined with soapstone, or magnetic iron ore, which forms the boshes. In most of these furnaces hollow cast-iron boshes are inserted all around the hearth, which are kept cool by a circulation of air, or blast; or, which is not often the case, by a circulation of water. Most of these furnaces are supplied with fresh air under the grate, by means of fan-blast. Two furnaces, to one fan of the kind described in figs. 269 and 270, which with a diameter of 3 feet, performs from 700 to 800 revolutions, is the form commonly adopted. In this case the ash-pit is provided with iron doors, and the blast conducted in canals under ground. Fig. 271 shows a perspective view of a plain double furnace from the chimney, with the charging door of the

FIG. 268.

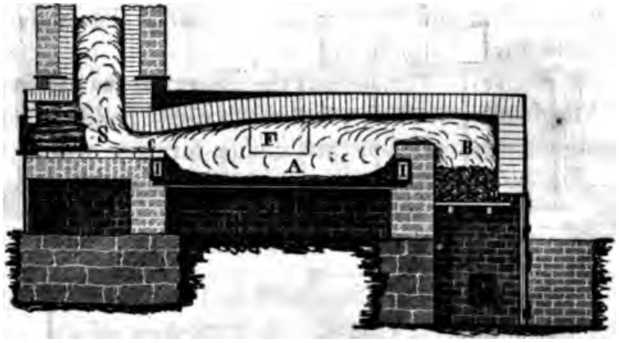


FIG. 269.

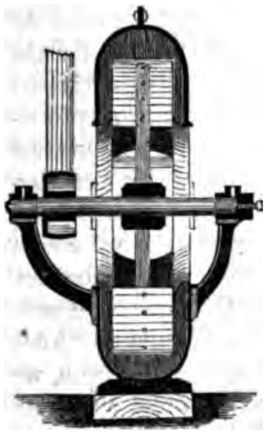
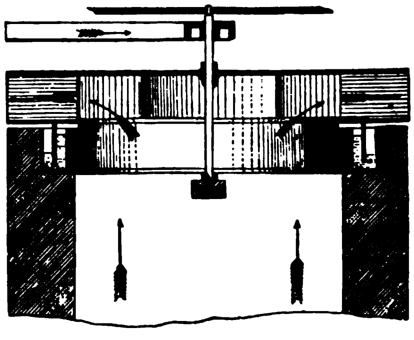


FIG. 270.



stove. This may be a sliding door, or a common one suspended on hinges; but it must be hollow so as to be lined with firebrick. The construction of a sliding door is shown in fig. 272. It is formed of a cast-iron box, lined with firebrick, which are firmly fastened in it by iron wedges. A work-door of the furnace which is represented in the drawing, is generally 24 inches wide, and 26 inches high, and 3½ inches deep. The aperture is wider on the inside of the side which is shown, than outside, so as to afford sufficient room for the tools.

Fig. 271.

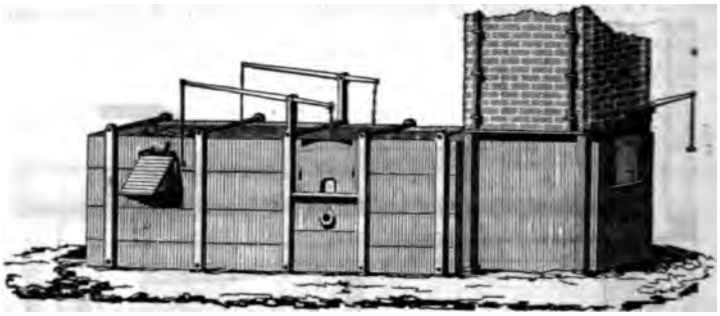
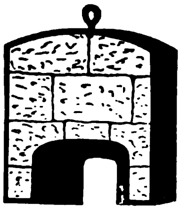
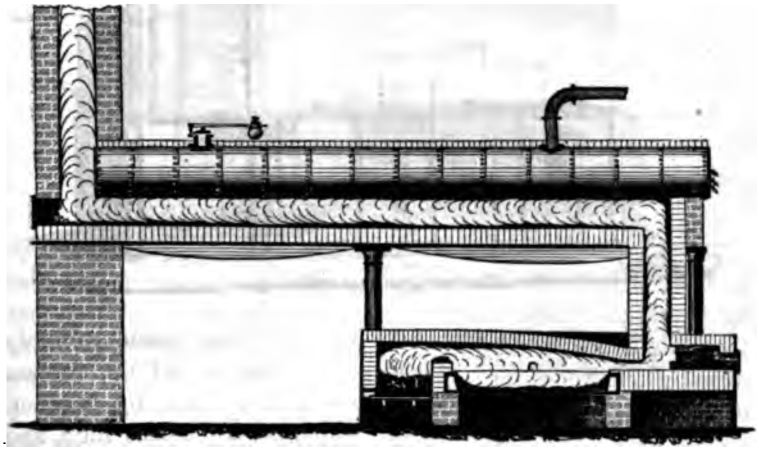


Fig. 272.



Most of the machinery in the iron works is driven by steam engines; and as a considerable quantity of waste heat is furnished by puddling furnaces, that is applied to steam boilers for the generation of steam. A variety of plans are proposed for this purpose; in fact, it is not difficult to advise a plan for the effectual use of the waste heat, particularly where the grate is supplied by blast. The most approved method appears to be to locate the steam boiler above the flue, or the stove, and conduct the heat along the boiler, and thence to the stack. The engraving, fig. 273, shows a section of such an arrangement, which requires no further description. In other instances the waste heat is conducted in flues directly from the furnace to the boilers, which are set in the common way, and on the same level with the puddling furnace; in this instance no stoves are used. After having given thus far the general forms of puddling furnaces, we may proceed to the description of the operation itself, which we will divide into two branches; that of puddling white-iron, and boiling gray-iron. In practice we find none of these operations perfectly done,—but it is necessary to describe both in order to show the distinct features of each, which cannot be explained without separating these two operations.

Fig. 273.



Puddling.—This operation is generally performed on white metal, which does not fuse perfectly. It is performed also on gray, or very fusible metal equally as well; and thus far the quality of metal does not exert any influence on puddling. It is the mode of operation, and the form of the furnace-hearth which determines either puddling or boiling. The following remarks apply to crude iron generally. As stated above, the depth of the bottom below the sill of the work-door, or the work-bridge, is never more than 6 inches, for good white plate metal; for impure fusible pig or plate, it is often not more than 2 or 3 inches. In the latter case a strong iron bottom is required, for very little cinder remains on it. In puddling, the roof is not often more than 18 inches and from that to 22 inches above the bottom.

A new furnace is gently heated for some days by a small fire, so as to prevent injury to the brick-work; after which the hearth is cleared from all sand and rubbish, and a layer of broken cinder mixed with hammer-slag, is spread 3 or 4 inches deep over the bottom, and gently sloped around the hearth towards the in-walls, so as to be at the walls somewhat higher than at the work-bridge. In this case the hearth is not always surrounded by iron boshes, and it assumes the form shown in fig. 274. To the cinder a strong heat is imparted, which melts it and forms a solid bed of cinder of 1¼ or 2 inches in thickness upon the iron bottom. The iron is now charged, either from the stove, when such is used, or the cold iron is thrown into the furnace, and spread uniformly over the hearth. The grate is supplied with fresh fuel, the grate-bars cleaned from clinkers, and the strongest heat produced which the furnace is capable of. The damper on the top of the chimney is drawn to its full extent, and when blast is used all that the furnace will bear is turned in. In good furnaces and with light charges and the use of a stove, 10 to 15 minutes are sufficient for heating the iron. A heavy charge and cold pigs require half an hour. In a single furnace not less than 350 pounds, and from that to 550 pounds of iron, form a charge; in a double furnace not less than 700, nor often more than 1,000 pounds are charged at once. When the iron is so heated as to be easily broken by the tools, the helper lifts the various pieces off the bottom, by means of the paddle or ringer—a long crowbar represented in A, fig. 275. This is provided at one end with a round knob. The part which is to be handled is in the form of an octagon. That part which enters the furnace is square, and terminates in a chisel-edge. Fig. B shows a hook, which is the other tool of the puddler; it is simply this ringer, bent at the chisel-end. These tools are made of square iron, 1 inch or 1¼ inch in thickness; and from 5 to 7 feet long, according to the width of the furnace. When the hot metal is lifted

FIG. 274.

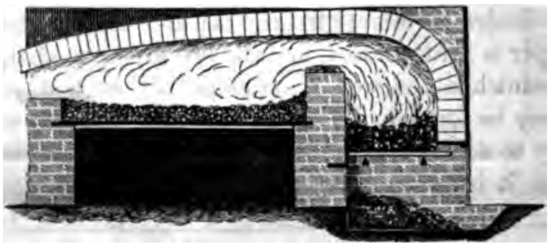
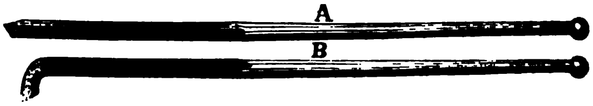


FIG. 275.

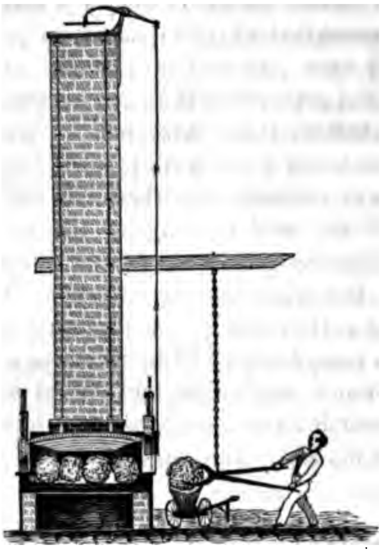


from the bottom, the damper is lowered, and the blast shut off so as to reduce or continue the heat as it is in the furnace. The metal is now broken by the hook into small fragments, which are diligently moved so as to mix and cover them perfectly with cinder. In continuing the work thus, all the iron mixes with the cinder in minute fragments; and when so far divided, the damper is gently raised, and the fire urged by charging fresh coal; meanwhile the iron is industriously worked, so that no lumps may be formed. With the increasing heat the iron begins gradually to adhere together; and in less than an hour from the beginning it is formed into small lumps of spongy iron, which feel more or less soft under the tool. At this time the puddler turns the iron once or twice rapidly over the bottom, so as to heat it thoroughly, when it begins to form larger lumps, or balls, or loops, by uniting small parcels. If the iron is uniformly hot and well soaked with cinder, it adheres easily together and loops are formed with great facility. If on the contrary it is cold, or dry, it does not weld and must be turned and exposed to heat until it sticks together. Balls are now formed, of nearly a round shape; and when all the iron is converted into balls of from 80 to 120 pounds each, they are drawn, by means of tongs, from the furnace and carried on a car or wheelbarrow to the hammer or squeezer, to be formed into blooms.

A pair of tongs is represented in fig. 276, suspended by a long chain, fastened above the furnace to a timber of the building. The wagon, as shown, is constructed of bars of wrought-iron, and is run on a flooring of cast-iron plates.

With ordinary attention a heat may be worked, on an average, within 1½ hours' time; the kind of metal used has no influence on the time. But the quality of iron made depends entirely on the quality of the metal used. When any improvement in quality is contemplated, a method of proceeding which inclines the metal to boiling, is adopted. This requires more time and labor than the puddling described above. In puddling, the object is fast work; and this is accomplished by using only a little cinder and commencing the work on the iron at a low heat, increasing it gradually as the operation proceeds. Weak metal will bear but little heat and little cinder; and if well worked and shingled cold, will make quite as fibrous iron as the best plate iron. But such puddled iron, of weak metal, changes its nature from fibrous to crystallized iron when heated to a higher degree than that by which it has been puddled. Good plate iron will bear a high heat throughout the whole operation, weak plate or pig iron will not; it must be kept and worked at a lower heat.

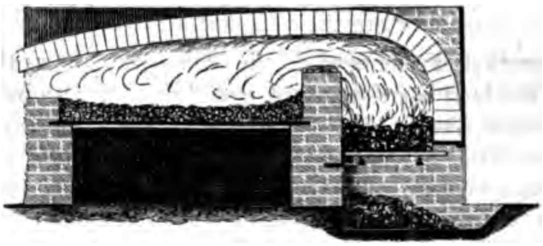
Fig. 276.



This operation is managed on the same principle as the other—that is, the heat is gradually increased from the beginning to the end. The welding heat on the balls of weak iron is not as high as that on iron of good metal. In all cases where puddling is contemplated it is advisable to chill the cast-iron, no matter if puddled directly from the blast-furnace, or if refined. Gray iron, or tempered metal—that is, metal cast in dry sand or coal-dust—does not puddle well; and whitened or chilled iron is not suitable for boiling.

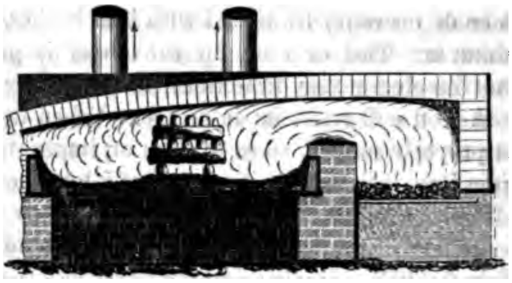
Boiling.—In puddling, it is a leading point to work with only a little cinder in the furnace; but in boiling the reverse is the case—the larger the proportion of cinder to the iron, the more advantageous is the result. In consequence of this, the operation of boiling is practised to a limited extent, because the necessary supply of good cinder cannot always be obtained. In this operation we are thus enabled to make good iron always, from any kind of metal, provided good cinder is in the furnace. Where good charcoal plate iron is puddled, a sufficient quantity of good cinder can always be obtained from one puddling-furnace to supply a boiling-furnace, if the metal to be boiled is of a good quality. Boiling is chiefly done to improve quality; it will, when properly performed, be always productive of a better iron than puddling. The bottom of a boiling-furnace is started and prepared in a manner similar to that of a puddling-furnace, with the only difference that a larger quantity of cinder is thrown into the furnace at once. Instead of 2 inches, at least 4 inches in thickness of solid cinder should be put on the iron bottom of the hearth. The bottom is for these reasons lower, but not deeper than 12 inches beneath the work-plate of the door. These furnaces must be of necessity furnished with iron boshes, no matter whether fluxes are used or not; for the cinder is generally so fusible as to dissolve stones, fire-bricks, or any other substance rapidly—cold iron will resist its influence. When the cinder in a furnace is properly melted, so as to form an impenetrable layer for the molten iron, it is pushed by means of a long hook, around the hearth towards the boshes, and cooled so far as to stick to them. The hearth forms now a concave mould, similar to that represented in fig. 277. In charging the pig-iron either from the stove, or cold, it is not distributed over the whole hearth, but more closely piled together so that the slag may be heated before any melted iron touches it; and in order to heat bottom and iron uniformly, the latter is frequently moved about while it is heating. At least 20 minutes are required for good pig-iron before the proper heat for work is obtained; for impure anthracite iron, or coke iron, half, and in some kinds of furnaces three-quarters of an hour. The mode of charging the iron has a peculiar influence on its quality, and necessarily on the quantity. Our own experience has led us to the conclusion that good metal, or in fact that for puddling, may be distributed over the whole

FIG. 277.



hearth, so as to work hot iron in cold cinder. When the boiling is to be carried out to perfection, cold iron ought to be worked in hot cinder. These expressions, of course, must be understood comparatively. When all attempts to make good iron of very bad or impure metal have failed, it may be done successfully if the iron is closely piled, and the furnace strongly heated before the work is started. We never failed to obtain first-rate iron, provided the cinder was of suitable quality and quantity, when the pigs were charged in the manner represented in fig. 278. In this case, the flue must be contracted to its narrowest limits, so as to cause the furnace to work slow and the heat on the pigs continued until they are all melted down without being moved. This melting requires generally a long time. The operation is not a practical one, for it causes slow work and a large waste of iron; but the quality produced may be depended on. The manner in which the iron is charged is not therefore a matter of indifference, or whether it is turned while melting or not. In boiling, it must be a leading object to heat the cinder in the bottom before the iron becomes heated so as to melt. The melting-in is therefore slower and more laborious, in boiling than in puddling. The chief object in boiling is to obtain good quality from inferior pig-iron; and as this necessarily requires a large portion of iron to be converted into cinder, the roof of the furnace is raised higher. It is from 24 to 28 inches above the bottom, so that the iron, either in melting or balling, is less affected by the flame.

FIG. 278.



In this operation the iron ought to be perfectly fluid when the work commences. The damper is then closed, and the heat of the furnace retained at the melting-point; fresh coal may be charged at this time so as to exclude the access of fresh air to the

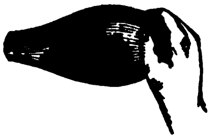


Fig. 279.

iron. The mass of iron and cinder is now diligently stirred; and when all the iron is perfectly dissolved, some moistened hammer-slag, or artificial fluxes are thrown in, while the tools are used in a timely manner. These substances should be introduced in small quantities at a time. About a handful of hammer-slag is taken in a small dish or scoop, such as is represented in fig. 279, and thrown into the furnace at the work-door. This operation is continued until the iron begins to boil, that is, rises or ferments. At a certain time, or after a certain quantity of flux is thrown in, the cinder rises; and then no more hammer-slag is required, for it will work its way without it. The mass is supposed to rise up to the work-plate, so that no cinder may flow from the furnace through the door; and then the fire is stirred and the damper drawn very little, merely to increase the heat slowly. If heat is now too rapidly applied, the cinder, which shows a slimy consistence, is melted and falls down, and the fermentation or boiling is at an end; little and weak iron is the consequence. The heat should be raised very slowly, by diligent work with the tools. Soon after the cinder rises to the work-bridge, white specks of iron appear on its surface and disappear quickly; by degrees groups of such particles appear in a rolling motion on the surface of the cinder, and as quickly disappear. The iron is now in small crystals, which float in the cinder; they are lifted to the surface by carbonic oxide—which is formed of the oxygen of the cinder and the carbon of the iron—and the gas, when discharged, restores the iron to its full gravity, and it descends again. We may here remark, that with gray iron and a moderate heat, blue flames of carbonic oxide appear at the surface of the cinder; with white iron, no matter how much carbon it may contain, no flames are visible; and we suppose that in this case carbonic acid is formed. When the heat is high on gray iron and much hammer-slag is used, no flames are formed—the gas from below the cinder appears and disappears without them. It is remarkable, that from equal qualities of pig-iron, the metal obtained when flames are formed is generally of a better quality than that produced without them. Shortly after the iron has thus risen to the surface of the cinder and under the influence of an increasing heat, the quantity of carbon in it is exhausted, and the fermentation ceases; the cinder falls down to the bottom and exposes the iron in a spongy mass, honey-combed, to the influence of the heat. This iron would soon weld together into one mass, if not prevented by the workmen. It is therefore industriously turned about, broken into small parcels, and exposed on all sides to the heat. When thoroughly hot it is formed into balls, withdrawn from the furnace, and shingled into blooms.

Boiling requires more time than puddling; a heat cannot be finished in less than 2 hours, unless the pig-iron is very good and cinder abundant. It requires more labor and more fuel than puddling. But by boiling, as good iron can be produced as in the best charcoal-forge, with more regularity, certainty, and uniformity. As good yield can never be obtained in a refining operation, as in boiling. The same kind of pig-iron which will yield but 80 per cent. in the charcoal-forge, or as much in being refined and puddled, will furnish with equal ease 95 per cent. of good iron in boiling. Some of the forges yield in boiling charcoal pig, from 95 to 97 per cent on an average; others only 90. Anthracite iron, from 85 to 90 per cent. Coke pig is generally run through the finery, and the yield in blooms may amount to 80 pounds from 100 pounds of pig. In the Western States bituminous coal is chiefly used in puddling-furnaces, and no blowers are applied. The use of coal there is about one ton to the ton of iron produced. In the Eastern States the blower is used throughout, either for bituminous or anthracite coal; and the consumption of coal is not often above 1800 pounds to a ton of iron—frequently as low as 1600, and even 1300 or 1400, in good furnaces and with good pig-iron.

General Remarks.—The best method in practice for working cheap, is to multiply the kinds of pig-iron, either for the charcoal-forge or for the puddling-furnace. The same point is important here as at the smelting-furnaces with ores and fluxes; the greater the number of the different kinds, the better for success. It will not be necessary to state why it is so; this has been done already. When various kinds of pig-iron are at disposal, they work best when all of them are mixed together in certain proportions. Such a mixture works faster, produces better iron, and yields more than a single kind. In order to enjoy these advantages, forges and rolling-mills should be separated from the blast-furnaces. The principle is so far a leading one in metallurgy, that some operations—copper smelting, for example—cannot be carried on to advantage without it. It is of most importance in manufacturing iron.

Pure iron is not the strongest; but that which contains the smallest amount of a certain kind of impurities, is the best in all instances. Steel, deprived of its carbon and other substances, is the strongest iron. First quality of German steel consists of (I) 98·06 iron, 1·94 carbon, a faint trace of sulphur, silicon, and copper. The best English cast-steel consists of (II) 93·80 iron, 1·43 carbon, 1·00 sulphur, 1·92 manganese, ·52 silicon, ·93 arsenic, ·12 antimony, ·18 nitrogen, and a trace of tin. The best Swedish iron, of which this steel is made, consists of (III) 98·78 iron, ·84 carbon, ·12 silicon, ·02 arsenic, ·07 copper, ·05 manganese. Bar-iron from Wales, good quality, contained (IV) 98·90 iron, ·41 carbon, ·40 phosphorus, ·08 silicon, and ·04 manganese. Very strong, compact, common charcoal iron (V) 99·13 iron, ·66 carbon, ·29 manganese, ·05 copper, and a trace of silex. When we examine some kinds of crude iron, we detect the cause of imperfections which are found in the wrought-iron manufactured of it. A first-rate crude white iron, of which the best German iron is made, consists of (VI) 95·20 iron, 2·91 carbon, 1·79 manganese, ·08 phosphorus, ·01 sulphur, and ·001 silicon. White crude iron from the same kind of spathic ore, but smelted for the manufacture of steel, contained (VII) 89·71 iron, 5·14 carbon, 4·50 manganese, ·56 silicon, ·08 phosphorus, ·002 sulphur. A gray coke, cast-iron, well qualified for the foundry, contained (VIII) iron 94·63, carbon 2·60, silicon 1·53, manganese ·50, phosphorus ·39, and sulphur ·35. Gray Scotch pig, Clyde, contained (IX) iron 92·30, carbon 2·20, silicon 2·80, phosphorus 1·30, sulphur 1·40. In comparing the composition of hot-blast and cold-blast iron, we obtain a still more comprehensive insight into the nature of the refining process. No. 2 charcoal iron, smelted by cold-blast, contained (X) 93·29 iron, 4·77 carbon, ·71 silicon, 1·23 phosphorus. The same ore and flux, smelted by charcoal and hot-blast of 470°, (XI) 91·42 iron, 4·15 carbon, 3·21 silicon, 1·22 phosphorus.

In these notices of assays we have neglected to allude to the difference which exists in crude iron, in consequence of having carbon chemically combined, or as a mechanical admixture; because we may, by cooling the melted iron suddenly, convert almost all the carbon into chemically combined carbon. In tempering, for instance, the white of assay VII, which has all its carbon chemically combined, we may convert that into a mechanical admixture. However little difference it appears to make in refining iron, whether the carbon is chemically or mechanically combined, yet it has some influence on the operation. All substances which are in a chemical combination, or simply dissolved in another, form, when oxidized, the highest oxides which can exist in atmospheric air. This is the case with all the metals dissolved in sulphur, or any other substance, even in metals themselves; and in fact it appears to be a general law of nature. Carburetted hydrogen always forms carbonic acid and water—never carbonic oxide and water, when burning in the air. If, therefore, we melt iron in the presence of oxygen which contains carbon in solution, whether it is white or gray, if melted at a high heat carbonic acid is formed. Thus it happens we do not see blue flames, when white or gray iron is boiled at a high heat. This circumstance has a favorable influence on the refining operation, provided the iron is free from silicon or nearly so, because it accelerates the removal of carbon; but when silicon is present, the case is different. We omit here to speak of sulphur, phosphorus, and other substances, because these belong of necessity to the class of chemically combined matter. Carbon has very little affinity for oxygen at low temperatures; and in the form of graphite, in which it is contained in gray iron, it requires a high heat to combine with it. But when heated to a white heat, it surpasses all other substances in affinity for oxygen. In that condition it will deprive silex, sulphur, phosphorus, and all the metals of their oxygen, or will prevent their oxidation. From this we easily may draw the conclusion, that impure white iron—such as hot-blast, coke, and anthracite iron, cannot furnish good bar-iron when it is melted in presence of oxygen, because the dissolved carbon will absorb the oxygen before other substances are supplied and removed; and as the iron is thus deprived of the best and most harmless means of fusibility, it crystallizes with a portion of chemically combined impurities, and forms short iron. The best means to refine such impure iron is to melt it at a low heat, and in the presence of carbon and cinder—such as the charcoal-forge affords—so as to retain the carbon until the other impurities are removed, and then expel it. This is the leading principle in practice with all iron which contains carbon in chemical union. It may be worked in the charcoal-forge, the finery, or by the various modes of puddling. The only means of succeeding in removing any injurious impurities is to retain the melted condition of such iron by carbon, so as to afford these impurities an opportunity to be oxidized and removed. For these reasons impure iron should find a hot bottom, and all cooling influences should be removed. In practice this cannot be observed, because of the expenditures in labor and materials.

The foregoing theory is not only correct when applied to white iron, but also gray iron; yet as the carbon in gray iron is not so combustible as it is in white iron, we always succeed better in removing impurities from the former than from the latter.

This explanation shows clearly, why all attempts have proved unprofitable to refine hot melted iron as it comes from the blast-furnace. The carbon in iron which is so hot as when it comes from the blast-furnace, is chemically combined, and consequently very combustible. It is consumed before the other foreign matter is removed; and when the crude iron is impure and deprived of its carbon, no strong wrought-iron can be expected.

We see, therefore, the principle on which refining ought to be conducted. In all cases of pure crude iron, we may work white iron at a high heat, so as to gain on time and fuel, and work on a cold bottom. The latter expression, of course, refers only to a dry bottom, or little cinder. Impure iron—such as all hot-blast iron, anthracite and coke iron—should be gray, and melted on a bottom with much cinder, so that the impurities may be oxidized by the oxygen of the cinder, and absorbed by its alkali before carbon is removed. This, of course, requires in many instances very much cinder, and that of an alkaline constitution. White impure iron cannot form pure strong wrought-iron, because it is infusible before the impurities are removed.

In practice, we follow exactly the rules which may be drawn from the foregoing theory. The best iron is made in charcoal fires which are surrounded by bad conductors of heat—such as stones or brick; and a lining of carbon is used over them, so as to prevent the contact of the metal with these in-walls. A little iron is worked at a time, and much coal is consumed. Charcoal fires, surrounded by iron linings, require good white plate-iron although they work better with gray-pig. White and plate-iron, is worked to more advantage in a puddling than in a boiling furnace. Gray iron only can be boiled.

Since boiling must be considered as the most profitable operation, and preferable to either the charcoal forge or the puddling-furnace, and since white iron is not suitable for this pur pose; and since further, any white iron may be converted into gray iron by tempering or annealing, the question naturally arises if it would not be profitable to temper all pig-iron before refining or boiling it. This is actually done in many instances where pure fibrous iron is demanded. In some parts of Europe, first quality of white cast-iron is converted, by chilling it in a similar manner as crude copper, into thin plates; these are. piled with small charcoal in a kind of bake-oven, and exposed to a gentle red heat for some days. The white crude iron is thus tempered, and found to be gray after that operation; it then forms in refining an extremely soft, malleable, and fibrous iron—while when refined from the white plates it forms a strong, but a hard iron, of the nature of steel. This tempering is partially performed in the stove of a puddling-furnace, and when properly attended to it is of good service. A stove ought, therefore, never to heat the iron so far as to melt it, or even to cause it to show signs of melting; and in order to enable the carbon and other matter to separate from the chemical union with iron, it ought to be at least red-hot. A stove must be close so as to prevent the access of fresh air; and if the pigs could be bedded in anthracite dust, and still heated to the necessary degree, the operation would be more perfect. As it requires a heat of some days in length to convert white cast-iron by these means into gray iron, a stove can perform that operation but very imperfectly; still, it adds something to the success when the iron is exposed to a red heat for one or two hours. All arrangements by which it is intended merely to melt the iron previous to puddling, and thus to operate on it, are unprofitable. The solid iron should be charged to the puddling-furnace, or the forge, or finery.

Wrought-iron is only a mechanical admixture of iron and foreign matter; it may contain a larger amount of the latter than even cast-iron, and be still very malleable and ductile. But an essential condition is that all the impurities should be free, without any part, or at least only a small part of it, in chemical combination with the iron. This distinguishes it from cast-iron and from steel. Wrought-iron may contain any amount of silex and be perfectly malleable, but it should not contain any silicon, or little of it, or silex and carbon; for the latter will reduce the first, and cause it to combine with iron again. On this principle we must be enabled to form malleable, or wrought-iron, by mere exposure to heat and oxygen; this operation is practised at present very extensively. When cast-iron is imbedded in chalk, or carbonate of lime—or any carbonate which does not melt at a red heat—and is exposed to a red heat for a few days, the previously brittle cast-iron becomes perfectly malleable. If this iron is again heated for a shorter time in oxide of iron, it is converted into white malleable iron, and may now be welded and drawn out like wrought-iron. Cast-iron which has been exposed to a red heat for a long time in the presence of carbon—as in gas retorts—is malleable, however impure.

Good wrought-iron should be as free from foreign matter as possible, notwithstanding that impure iron may be very strong and perfectly malleable; for all this kind of iron is expected to resist heat in the presence of carbon, without being essentially altered. This latter condition is not complied with in impure iron; it either becomes brittle or rotten, after being repeatedly heated. Of all the foreign admixtures to iron, silicon adheres the most tenaciously to it, and causes it to be brittle. The amount of this substance is particularly large in coke, in anthracite, and in all hot-blast iron. It reaches from 3 to 4 per cent. in most of the latter kinds of pig-iron. Almost all other impurities of iron may be evaporated in the heat of the furnaces and cause no other loss than the amount present in the metal, or the impurities are converted into acids and absorb but little of the metallic oxides. It is not so with silicon, neither in its metallic state, nor when oxidized to silica. If it is volatile, it will resist any amount and intensity of heat., Silica is composed of 48·04 silicon, and 51·96 oxygen in 100 parts. Crude iron, therefore, which contains 4 per cent. of silicon, will form at least 8 parts of silica; and that which contains 3 per cent., at least 6 parts of silica. The latter amount occurs in every kind of hot-blast iron. In refining iron, the amount of silica absorbed by the slag is in proportion to the capacity of that slag for silica; and as the quality depends on the absence of silica and other substances, the cinder with which the melted iron is brought in contact ought to contain little of it, so as to have a strong capacity for absorbing that substance.

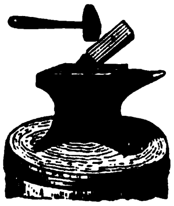
Cinder by which a first-rate quality of Swedish iron is produced, contains only from 7 to 8 parts of silica in 100 parts; and if all the metallic bases must be furnished by the pig-iron, not much can be left of hot-blast iron, for it represents nearly the composition of such cinder. Assuming 4 per cent. of silicon to be present in pig-iron, it is equal to 8·3 silica; if it is saturated to the above degree with protoxide of iron, it requires 71·3 pounds of metallic iron for forming so much protoxide. Of 100 pounds of pig-iron there are left, therefore, 91·7—71·3 = 20·4 pounds, which may be converted into good wrought-iron. Cinder from good common charcoal-forge iron, contains 22 parts of silica in 100 parts of slag; this would afford 33 pounds of good charcoal iron from 100 pounds of hot-blast pig-iron. Good puddling cinder is of a similar composition as the latter; it contains from 23 to 30 per cent. of silica. This shows clearly that in refining impure or hot-blast iron, either a large quantity of silicon must remain in the iron, or great loss must follow from its removal.

In order to save iron and still remove foreign matter from it, fluxes are used, or such substances as will combine with its impurities. Of all the various forms of working, the puddling-furnace, together with the boiling operation, is the most suitable and effective for the application of such fluxes. The number of materials which may be thus applied is very great, so far as theory indicates; but very limited in practice. The mode of application is similar in all instances; the fluxes are either charged with the pig-iron, or after that is melted. They may be also divided, and partly charged with the cold pigs, and another part thrown in when these are melted. The kinds of fluxes which may be and are used, are forge cinder, hammer-slag, squeezer cinder, and pulverized magnetic ore; these are the most common. A large part of them is always charged with the pig-iron, forming a layer for the latter. Hammer-slag is generally thrown in when the iron is melted, after having been well mixed with the hot slag. The governing principle thus in operation, is the oxidization of silicon by the fluid slags. Hammer-slag, or magnetic ore, furnishes oxygen too freely to silicious iron; and for these reasons it is reserved until the iron is thoroughly mixed with the melted slag. Water is also used at this time; it cannot form a flux, it merely furnishes oxygen by being decomposed, and consequently does not prevent the oxidation of iron. In addition to these fluxes, common salt is used. This does not saturate any silica, and has no influence upon that substance, but its presence causes the slag to be more fluid; and if any phosphates are present, the acid is driven off from them by chlorine. When much chlorine is present, the refined iron is rendered cold-short by it; this brittleness is easily removed in reheating. Such iron generally forms very strong malleable iron; it is reheated and drawn. Chlorine does not remain in large quantities in slag, and it is of no use to apply more than a quarter of 1 per cent. of the melted iron. The presence of clay, or lime, causes it to be more permanent than in union with other matter; and as lime is not a good substance in these puddling cinders, clay is preferred and mixed with the salt. Carbonate of potash or of soda, appears to have little or no effect on iron in this instance; which must be ascribed to its being evaporated in the strong heat of the furnace. I have melted these substances together with other good forge slags at a low heat, and used the composition thus formed; but it proved to be of as little use as other modes of application. The most effective compound of this kind is common salt, mixed with clay and a little hammer-slag, or iron ore, or black manganese, and exposed to a red heat for some hours in an iron pot, so as to expel a large portion of chlorine. The brownish-red substance thus obtained works exceedingly well. It is added to the iron in small quantities at the time when hammer-slag is commonly applied. When pig-iron contains phosphorus, if a small quantity of lime in the form of chalk, or pounded-limestone is added to the charge of cold iron, it does no great harm—still, the iron is better without it; pure clay performs the same services, without having any injurious effect on the iron. Black manganese is a very good flux, but in its application to silicious iron much caution is required; it furnishes oxygen so readily that silicon cannot be oxidized—carbon absorbs all the oxygen. For the same reasons, peroxide of iron cannot be employed to advantage. Other fluxes—such as saltpetre; oxides of metals, as those of lead, zinc, and others—are of no practical use; they are expensive, and do not in the least enhance the value of iron. If any additions to impure iron are useful, they are those of arsenic, phosphorus, or sulphur, provided they are intimately combined with the crude iron, so as to cause it to retain its fluidity until silicon is removed. These substances are easily driven off by a little chlorine, or the addition of a little salt. But thus to combine iron with phosphorus, so as to cause it to be fluid, is too expensive, because it requires remelting at a low heat. The best means to prepare this inferior metal, in which all the impurities have been chemically combined in the high heat of the blast-furnace, is to expose it imbedded in fine charcoal, coke, or anthracite, or limestone, to a gentle red-heat, and oxidize the silex by these means. This affords sufficient carbon for remelting in the puddling-furnace, and an easy removal of silica. For ordinary purposes, this operation is too expensive.

Steel.—This modification of iron is, in many respects, the most interesting of all alloys. No metal, or alloy, is superior in strength to steel, and very few are harder. Formerly, it was the general opinion that steel was only carbon and iron; recent chemical examinations have shown that the best cast-steel contains a variety of substances, which are considered essential to its constitution. After what has been said on alloys generally, and on those of iron in particular, it is not difficult to understand the relation in which carbon stands to iron; and there is no doubt as to the necessity that it should be present in iron, in order to constitute steel. It has been decided by experiments, that iron which is free from other substances, and contains less than ·65 per cent. of carbon, does not assume that hardness which distinguishes steel; it forms hard iron. From 1·4 to 2·3 per cent. of carbon appears to be the other extreme; when iron contains more than that amount of carbon, it becomes porous and brittle, and is cast-iron. We find, so far as carbon is concerned, that iron with less than ·65 per cent. of carbon is wrought-iron; from that to 2·3 per cent. of carbon, forms steel; and when the quantity of carbon is larger, the metal is considered cast-iron. There are other substances which impart hardness to iron, and perform in that respect a similar office to carbon. Steel which is peculiarly elastic, Brescian-steel, consists of (I) 98·06 iron, 1·94 carbon, and faint traces of sulphur and silicon. A German steel, equally as suitable for cutlery and edge-tools, contains (II) 97·88 iron, 1·70 carbon, ·04 silicon, ·38 copper, and traces of sulphur and tin. Common English cast-steel, contains (III) 97·94 iron, 1·72 carbon, ·22 silicon, ·07 copper, ·02 manganese, ·007 arsenic. It has been shown in page 575, assay II, that the best cast-steel contains the smallest amount of iron—93·80—and also a small amount of carbon, 1·43; but a large number and amount of other substances. The assays I and II, are of German steel, made in the charcoal-forge directly from crude white iron smelted of sparry ore. Assays II and III—page 575—are of converted cast-steel. The wrought-iron of which the latter is produced, contains already some of that foreign matter which we observe in the steel, and such as carbon, sulphur, and phosphorus, in a larger quantity.

Hardening.—Any substance which combines chemically with iron, will impart hardness to it; but the presence of carbon is required, in order to produce that peculiarity, softness after tempering, which we observe in so high a degree in steel. Other substances, which have sufficient cohesion, produce a similar, but weaker, effect on iron than carbon, such are sulphur, or arsenic, and perhaps others; but no other substance is more available and more perfectly suited for this purpose than carbon. When the difference between hardened and tempered steel is caused by carbon, or any other substance, in chemical union, in the hardened, and in mechanical admixture in tempered steel, it is evident that this condition must be dependent upon temperature or other agencies. German steel, manufactured at a high heat, requires a white heat for hardening, and its carbon is so firmly united to the iron that this kind of steel may be welded to it with great facility. Refined shear-steel, which has been much heated and hammered, will bear, next to German steel, the highest heat in hardening and welding. Ordinary cast-steel will bear less than shear-steel, and is welded with difficulty; the finest cast-steel will bear the least degree of it, and cannot be welded to iron by the common process. This shows that a large quantity of foreign substances cause the steel to be more fusible, and to bear less heat in hardening. The degree of heat by which the chemical union of carbon and iron is accomplished is therefore not permanent—it varies with the fusibility of the metal. This we observe as well in cast-iron as in all other metallic alloys. The change in the constitution of steel may be produced at very low temperatures, indeed at almost any temperature. The finest edge, and a high degree of hardness, are produced by the mere hammering of steel; and, if the above theory of the constitution of hardened and tempered steel is correct, the mechanical mixture of carbon and iron in tempered steel is converted into a chemical compound by mere compression. We recognize this fact in drawing wire, sheet iron, or in hammering iron, or any other metal or alloy. In these operations a large quantity of heat is liberated by compression, which may in some measure account for the metamorphosis; but we find that, when the compression is very rapid, and brought about by great force, the phenomenon attending its application is similar to that of a strong heat; the metal becomes extremely brittle. The best edge, and consequently the highest degree of cohesion and compactness in steel, is produced by striking a small bar of tempered steel, with a small steel hammer, on a cold polished steel anvil, so as to avoid any considerable or perceptible increase of heat. If this operation is performed on a square bar of steel, in the manner represented in fig. 280, by means of a hammer of the smallest size, of one or two ounces weight, and the corner of the steel, thus compressed, is ground down so as to remove the surface which has been touched by the hammer, we obtain an edge which cannot be surpassed for fineness by any other means of hardening. This shows that hardening may be performed by a variety of means, and that heat is not absolutely necessary. The strong cohesion of the metal is the cause of this phenomenon; and by whatever means we produce the close contact of the particles of metal and carbon, we secure hardness. These reflections serve to explain the manipulations which are employed in the manufacture of steel.

Fig. 280.



The common means by which steel is hardened are well known; these form no part of our investigations; but we may remark, that it is not so much the degree of heat to which steel is exposed, before chilling it, as the difference of temperature between the cooling medium and the heat of the metal, together with the heat-conducting capacity of the refrigerator. Experiments have shown that little is gained by substituting other fluids than pure water for hardening steel. This is an entirely practical operation: the temperature of water may be in all instances the same, and fresh common spring water, or river water, is as good as any other fluid. But, as the liability of steel to lose some of its component parts increases with the heat to which it is exposed, and as, near its smelting point, it assumes the nature of cast-iron, it is found necessary, in order to preserve its original character, to perform the hardening operation at the lowest possible heat; for these reasons water as cold as possible is used, and as, by plunging the hot metal into it, an atmosphere of steam is formed around it, which is a bad conductor of heat, either the metal or the water ought to be moved, to expose the hot metal to renewed action of the cold particles. The application of acids or salts, for hardening, is injurious to steel, however good conductors of heat such solutions are. Some of the fluid will always penetrate the metal and cause its decomposition. The use of oil or fat for this purpose is, if not equally prejudicial, at least of little benefit. That fluids penetrate metals, and particularly iron, is shown in wire factories, when iron wire is cleaned, after annealing, in diluted sulphuric acid, which is, by neutralization and washing, as far removed as practicable, it retains always some of the acid, which causes the wire to be brittle when fresh. An exposure of the wire to the atmosphere for some time removes the acid, and therefore the cause of brittleness. Wire thus cleaned by acids is often permanently injured in its strength, which does not happen with wire which is cleaned by the old method, with sand and water.

Annealing.—It has been recommended, and it is also practicable in some instances, to modify the heat of the metal and the cooling medium for hardening, so that the contact of the two produces the required degree of hardness. A uniform degree of heat cannot be applied to all kinds of steel; and since the mode and time of heating is also important, and the fluid refrigerator cannot be uniform in composition and temperature, it is easily understood that this method of hardening cannot be universal. The common mode, and perhaps the best one for hardening, is to expose the steel to such a degree of heat, and so to cool it in water, that it assumes the highest degree of hardness, and then temper by exposure to a moderate heat. A variety of means have been proposed for tempering hardened steel, such as melted fusible metals, lead and alloys of lead, heated fat or oil. When we reflect on the nature of steel, we soon find that the various kinds require different degrees of heat, by which they assume a definite texture or hardness, and that neither a certain degree of heat nor a certain color of its tempered surface will indicate the actual condition of the steel. The operations on steel are of so delicate a nature that they cannot be brought under general rules—they are entirely dependent on the skill of the practical man; no language can impart that information which is applicable in all cases. The following statements are for these reasons to be considered as relatively true, and not as generally applicable. Steel which has been hardened to the extreme should be exposed to a heat of 400° for chirurgical instruments, such as lancets; it assumes then a faint yellow color on its polished surface; to 425° for razors, which tempers it yellow; to 432° for penknives, which it also tempers yellow; to 468° for scissors and cold chisels, the color is brown yellow; to 490° for edge tools and common cutlery, color purple; to 508° for table knives, color also purple; to 530° for small springs and weapons; to 537° for large springs, saws, augers, the color is blue; to 580° for large saws, the color of which it tempers to dark blue; beyond 600° steel becomes black, is annealed and soft. Steel which requires a high degree of heat for hardening, demands also more heat for tempering than that which hardens at a lower degree of heat; and steel exposed to a tempering heat of a certain degree, for a length of time, increases in softness, even when the intensity of heat is not increased. The color of steel in the fresh fracture is white, like deadened silver. When tempered, it becomes more gray; and when annealed, it is gray, but the intensity depends on the kind of steel or amount of carbon. In all cases the hardened, as well as the annealed steel, should not exhibit to the eye, even when aided by a lens, any crystallization. Hardened steel shows a little higher lustre than annealed steel. In making these distinctions, we should always regard hammering as equal to hardening by heat and refrigeration. Excepting the peculiarities consequent upon hardening and tempering, steel is extremely strong; the resistance to rupture, in good annealed steel, is 110,000 pounds to the square inch; when hardened to the extreme, it is not so strong; but if tempered to a yellow color, it will carry 150,000 pounds. Its resistance to crushing and a permanent alteration of form, are equally distinguished. Steel is not very ductile. When cold, it will not bear much alteration of form, and when heated, it is, in some kinds, equal to iron. Cast-steel will not bear much bending. German steel, shear steel, and all kinds of hammered steel, are more ductile when hot than those kinds which have been less subjected to compression. The specific gravity of steel is 7·62, and from that to 7·81; in some very compact kinds, 7·9. Glass-hardened steel occupies a larger space than tempered steel: the same kind which was 7·75 when annealed, had a specific gravity of only 7·55 when hardened. These modifications of specific gravity are, of course, subject to the degree of heat by which the steel is hardened, and to its constitution. The degrees of heat at which steel melts vary considerably: German steel requires the highest heat for melting; this may be about 3,600°; the best kinds of cast-steel will melt at considerably less, or about 2,800°. Steel possesses a remarkable quality of retaining magnetism, or of being affected by the magnetic currents. Soft fibrous iron assumes that quality quicker, but does not retain it so long. Oxygen has little effect on hardened steel; still, white cast-iron, with much carbon, is superior to steel in resisting oxidation. The pure white color of hardened steel, and its susceptibility of being oxidized when heated, cause the beautiful colors of tempered steel. When heated under a cover of oil, these colors do not appear; or, when such colored and heated steel is brought into an atmosphere of hydrogen, the color also disappears. This shows that the color is caused by oxidation, and that, in tempering steel under a coating of oil, extreme caution is required to hit the proper point of heat. These colors proceed from a coating of oxide, which, in its extreme thinness, causes the yellow, and when thick, blue; and finally, it becomes opaque, and is black. Acids facilitate the formation of these colors—alkalies delay or prevent them altogether. Pure iron requires a higher heat, to show the same color, than steel; the best steel, and also white cast-iron, will show the series of colors at comparatively the lowest degree of heat.

Nature of Steel.—Before proceeding to the manufacture of steel, it will be of service to the better understanding of the operation, to enter briefly on an examination of the nature of steel, so far as it can be inferred from our experience with it. Steel is iron, with more or less impurities or matter alloyed with it; the same is true of cast-iron, and also of wrought-iron. We have seen that the quantity of foreign matter has no influence in determining what is steel, or cast-iron, or bar-iron. Still there is a vast difference in the form and nature of these various metals. White cast-iron, smelted of pure sparry ore, is hardly inferior in hardness to diamond; but it is extremely brittle, and cannot be tempered except by an extremely slow process of annealing. This crude iron contains, on an average, five per cent. of carbon, and a variety of other matter, all in chemical union. Those kinds of this iron which are suitable for natural steel, contain but little silicon; and those in which it abounds, say 1·5 to 1·8 per cent., or more than 1 per cent., are not used for steel, but converted into, and form a very strong wrought-iron. The quantity of iron in this crude material is not often more than 90 per cent. The finest kind of cast-steel contains nearly an equal amount of impurities with this cast-iron, but it is a different metal altogether. This steel can be forged, almost welded; it does not become perfectly fluid without injury, is easily tempered and annealed, and extremely strong. White cast-iron is not so; it melts very fluid, cannot be forged nor welded, cannot be tempered nor annealed nor hardened like steel. Wrought-iron shows very different qualities to these, and still may contain a similar amount of impurities. When good, pure wrought-iron is melted in a carbon-lined crucible, at a high heat, a kind of brittle steel is obtained, which has similar qualities in respect to hardening, tempering, &c. It would be impossible to arrive at a true theory on the nature of steel by comparing the quantitative constituents of steel, wrought-iron, and cast-iron, if it was not for one particular substance which imparts a most decided character to iron, and that is silicon. This has the strongest affinity for iron, is always present when there is carbon, but oxidizes quickly as soon as the latter disappears. In good steel we find ·2 per cent. of silicon, and from that to ·5 per cent. If the quantity is larger, the iron becomes brittle, and must be classed with cast-iron. Wrought-iron may contain less than this amount of silicon, or more; if very little, or not any carbon is present, the silicon will oxidize, form silex, and the iron may be very strong, malleable, and in fact belong to the best qualities of its kind. Most kinds of pure wrought-iron contain less silicon than converted steel or cast-steel, from which we conclude that iron absorbs silicon, along with other matter, in the converting box. Wrought-iron is an irregular mixture of silicious iron and pure iron; the atoms of the impurities and the metal are not uniformly combined, the equivalents are not grouped together in compound atoms. Imperfect kinds of wrought-iron are more irregular than those which have been carefully worked and purified. Good steel must be considered an extremely homogeneous body of compound atoms; an irregular iron cannot, therefore, form good steel, however pure it may be on the average. The most uniform iron, free, or nearly so, from silicon and silex, will therefore form the best steel. Silicon has a great affinity for iron, and cannot be removed from it but in the presence of such matter as causes it to be sufficiently fluid to expose the atoms of it to oxidation. This matter must be of such a kind as to be more easily removed than silicon, such as carbon, arsenic, sulphur, phosphorus, and some others. Iron for the manufacture of steel cannot, therefore, be refined successfully except in the presence of considerable charcoal, in a cinder which is rich in peroxide of iron, so as to absorb the silex as it is liberated. The charcoal forge—good, fusible, gray, pig iron—much work—and small charges, are the means by which a good result, for use in the converting box, may be achieved.

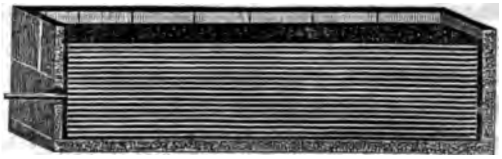
Natural Steel.—German steel, Indian wootz, steel made directly from the ore, and similar kinds of steel, are not manufactured in this country, and we do not expect ever will be.

All these kinds are more or less imperfect, irregular in quality, and expensive; or at least would be highly so, if manufactured here. In order to manufacture good, uniform steel, it must be melted, or often refined, which requires the use of much coal. The latter operation will, after much labor and attention has been paid to it, produce only a mixture of iron and steel, such as Damascus steel, a substance by far too expensive, and unsuitable for our peaceable occupations. German steel is not so very expensive in its manufacture; but, when all the operations have been performed which are necessary for the production of a good article, its cost is considerable, and would not, after all, answer our purposes. The only practical method, in this country, is to convert iron in the cementation box, and refine or melt the blistered steel. This is an operation generally known and practised. For these reasons we shall omit all explanation of any other method of manufacturing steel than that in use.

Steel of Cementation—Blistered Steel.—When soft, pure wrought-iron is imbedded in charcoal, and exposed to a red heat for some hours or a day; it is covered with a thin coating of steel, which assumes the hardness of fine steel when suddenly thrown into cold water. This operation is frequently performed by the blacksmith, and known as case-hardening. When it is continued during a week or ten days, an iron bar of ½ or ¾ of an inch in thickness is wholly converted into steel. The operation on the large scale is similar to that in the blacksmith shop, with the only difference that a large quantity is cemented at once.

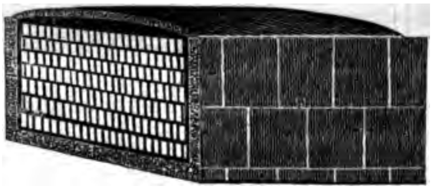
The converting or cementing box is represented in fig. 281. It shows a longitudinal and vertical section, as it is charged with iron and cement. Such boxes are from 10 to 20 feet in length, and not often less than 15 feet; from 2 to 4 feet in width, and not more than 30 inches in height. All large and high boxes work irregularly and slow. There is nothing gained in making the section more than 6 square feet; that is 2 feet high and 3 feet

FIG. 281.



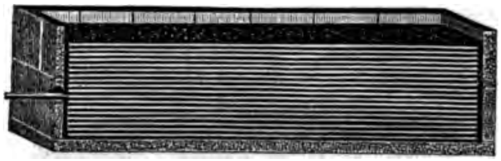
wide in the clear. A box which takes from 8 to 10 tons of small iron, that is iron of ⅜×1½ inches, or 12 tons of ½×2 inches, will require 16 tons of slabs. There are also boxes which take 20 tons of slabs. They are made of sandstone slabs, but in this country most generally of fire-tiles, that is of slabs made of fire-clay, well worked and baked, in a manner similar to fire-brick. They are from 12 to 15 inches wide, and as long; or if a box 24 inches high is to be made, they are as long as the height of the box. Two inches, and from that to 2½ inches, not often 3, is the thickness of these tiles. The boxes are put together by using fire-clay as mortar, like furnace work in fire-brick, and if well constructed a few more joints do no harm. It is, therefore, of not much advantage to employ large slabs; which is the more apparent when we consider that they are not always of so good quality, and more liable to break than small tiles. The more important object, in constructing a converting box, is to secure all the joints well with good fire-clay mortar, so that the trunk may be perfectly air-tight, as far as porous bricks will admit of it.

FIG. 282.



The iron bars are charged in the box in the manner shown in fig. 282. The rods are always flat iron, of the form of wagon-tire. In some of the steel works, slabs or plates, of from 30 to 40 pounds in weight, of ¾ or ⅞ inches in thickness, 5 or 6 inches wide, and 15 or 20 inches long, are used for conversion. The leading principle in selecting the form of iron, is the quality of steel to be manufactured of it. For spring-steel, heavy saws, agricultural implements, and common steel, slabs may be converted, and rolled or drawn under the hammer into bars. Shear-steel, or that refined steel which is manufactured of blistered steel by being fagotted, welded and drawn, is generally made of small bars ½×2 inches. Cast-steel, which is in some instances exposed to two or three converting heats, with fresh cement, is in bars of from ⅝×3 or ¾×3 inches. The iron bars should never touch each other in the box; a layer of cement at least ½ an inch in thickness must be between them. In charging a box, a layer of cement about 1 inch thick is sifted uniformly over the bottom, and upon this the first layer of iron is set edgeways. The bars are set one inch, or a space at least equal to their thickness apart, and as far from the sides. Over this first layer of iron sufficient cement is sifted to fill all the spaces between the bars and cover them about an inch in thickness. Another layer of bars is now laid in a similar manner as the first and covered with cement; and the operation is continued to within a few inches of the top. It is not necessary that the bars should be of the whole length of the box: long and short pieces may be put together so as to fill up the length. At each end of the box, a space of at least one inch is filled with cement. Through the centre of one of the heads of the box, as shown in fig. 283, some rods, trial-rods, project: these ought to extend at least half the length, or to the centre of the box. The aperture thus formed in the end is closed by fire-clay or sand. The necessity that one layer of bars should correspond with the interstices of the other, is obvious; for this reason it is not profitable to insert the bars in a flat position. The last layer is covered with half an inch of fresh cement, and upon this two or three inches of old cement is laid; the whole is then covered by a layer of fine moulding-sand. Or a better material for this purpose is the fine sand from grindstones, where wet grinding is performed. This is a mixture of iron and sand, and becomes extremely hard on being heated. The chest then assumes the form shown in fig. 282, and is ready for being fired.

FIG. 283.



Cement.—The cement consists of ground charcoal, which ought to be made of hard wood, and be strong coal. As it should be granulated, like that used in refining sugar, it is ground coarsely in mills, and the dust from it removed by sifting. Charcoal cut by a knife, similar to that for cutting straw, forms a suitable grain, and with little or no dust. The granulated charcoal is in some instances mixed with soot, but this addition is not necessary, and may be injurious if the soot is not very pure. In all cases, about one-tenth in volume of wood ashes is added, and well mixed with the charcoal and some common salt finely ground or in solution. Ground coke, anthracite, and all other additions to them, have proved of little or no use, and in most cases are injurious to the steel. In fact, good, pure, hard charcoal, with the addition of a very little salt in solution,—about a peck to a box,—sprinkled over the granulated coal, forms the best steel. There may be instances where the addition of some substances to the cement proves advantageous, but these are applicable only to peculiar kinds of iron and peculiar steel, and may serve in the manufacture of cast-steel only. For shear-steel, welding-steel, and those kinds of steel which are, after conversion, exposed to much heat, all such additions must prove injurious to the quality. There is no difficulty in combining, in the converting-box, any substance with iron. In adding sulphur, phosphorus, the oxides of volatile metals, such as antimony, arsenic, lead, bismuth, and others, they combine readily with the iron; and it may be true that such combinations are of advantage where a very uniform cast-steel, such as that for mint-stamps, is required. These additions will cause cast-steel to be more fusible, and those veins may be removed which often prove hurtful to fine stamps.

Furnaces.—One or two, and, in some instances, three boxes are inserted in one furnace. Large ones of 20 tons in capacity are inserted singly, and the furnace assumes a form such as is shown

FIG. 284.

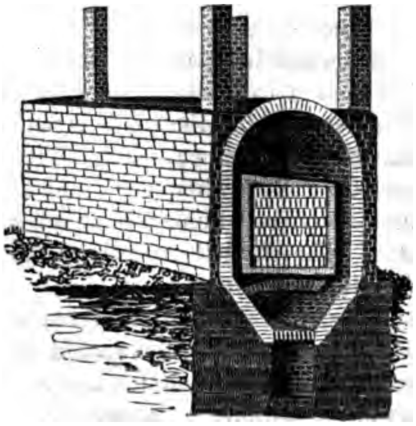
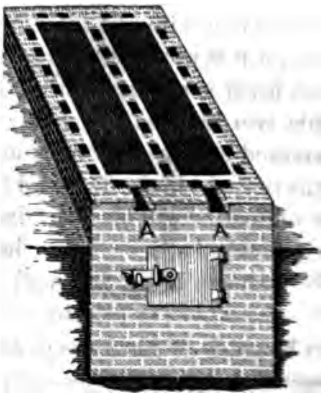


FIG. 285.

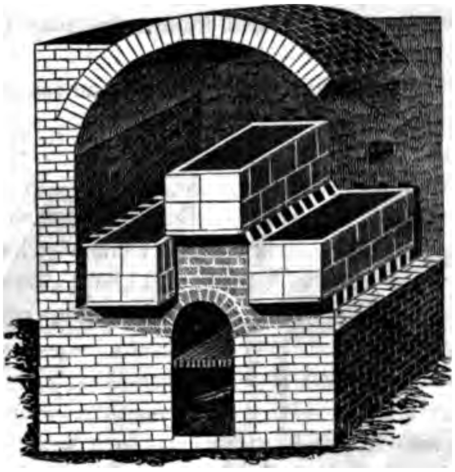


in the vertical section, fig. 284. The fire plays throughout the whole length of the bottom, and escapes by a series of flues formed of firebrick around the box. The heat is thus active on all sides, and also on the top of the box. The rough wall incloses an arch of firebrick sufficiently high to admit of the entrance of the steelmaker for charging and discharging the box. The arch is provided with a series of flues, leading to low chimneys. By shutting or opening these, the heat of the furnace is regulated; it is increased or diminished at one end or the other as circumstances may require. The grate of the furnace is below ground.

When two boxes are inserted, the arrangement of the furnace assumes the form represented in fig. 285. The system of flues around the boxes is here shown, with the apertures A A, for the trial bars, and the furnace door. The size of the flues is from 6 to 7 inches square, the partitions are of the thickness of the width of a firebrick.

In inserting three boxes, the arrangement is such as is shown in fig. 286. The space between the two lower boxes must be as wide as the width of the upper box, or nearly so.

Fig. 286.



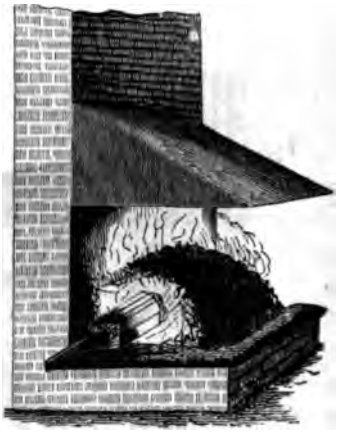
The size of the grate in these furnaces depends in some measure on the kind of fuel used; but as it is at least 20 inches wide in a single furnace, and extends the whole length of the box, not much more width is required in a double or triple furnace. The best fuel is anthracite coal; wood is most generally used, but there is no objection to either stone-coal, or coke, or, in fact, any kind of fuel, for only a cherry-red heat is required. Above the boxes there is an aperture of 2 feet square in the rough side-wall, for charging and discharging the contents of the boxes; these are commonly closed by an iron door, but may be walled up temporarily by bricks. The proof-holes extend also through the rough-wall. The height of the chimneys, and that of the conical hood, has little influence on the effect of the furnace; when they produce sufficient draught, and carry off the smoke, their height is sufficient.

From six to eight days, or with large boxes ten days, are sufficient for finishing a heat. The fire is started gradually, and kept low for the first few days; but afterwards it is gradually increased to a high red heat, which is continued to the end of the operation. The conversion proceeds more rapidly at a high heat than at a low one, and may thus be accomplished in a shorter time, but the steel is not uniform. In the interior of the box, when the fire is urged too much, the bars are not sufficiently carbonized, and the danger of melting them near the bottom is very great, which, if it happens, transforms the steel into cast-iron. The trial-bars, being in the centre of the box, will indicate the progress of cementation; and when they are found to be sufficiently carbonized, the flues and doors are all shut, and the furnace suffered to cool slowly. As a trial-bar once withdrawn from the furnace, cannot be returned, two or three such bars are inserted, so as to afford a repetition of the test. About an equal time, at least four or five days, are required to cool the furnace. The steel-maker now enters it, takes off the cover of the boxes, and hands out the converted bars; he then removes the cement, which in small quantities may be mixed with fresh, and fills the boxes again for a new operation. A heat consumes, including charging and discharging, about three weeks.

The steel thus obtained is not uniform in quality; that near the bottom and sides is more carbonized than in the centre. It is broken and assorted, and those bars which are not sufficiently carbonized are returned to the box to be cemented once more. The appearance of the steel is in some measure indicative of its quality. A brilliant white color and lustre in the fracture is a good indication; very large crystals forebode rather too much carbon for common steel, but not for cast-steel. The centre of the bar is always less carbonized than the exterior. Large irregular blisters show inferior iron. When the latter is uniform in texture and composition the blisters are uniform, and about ¾ of an inch long, and ⅓ an inch wide, uniformly distributed over the surface of the iron. Small and large blisters on the same bar are indicative of bad iron. Coarse iron, and puddled iron, hardly form blisters, or, at best, very irregular and broken elevations; such iron is too porous to bulge. The cause of these blisters is plain. Wrought-iron contains oxidized matter, and the carbon of the cement in entering its pores will form carbonic acid gas, which, in the endeavor to escape, makes the hot and malleable iron form a thin shell, in which the gas is inclosed.

Shear-Steel.—Blistered steel as it comes from the box is ready for common use; the better qualities are fagoted, welded, and drawn under the hammer into bars. The latter process, on being repeated two or three times, causes the steel to be uniform, and suitable to be welded to iron. Welding is performed in a smith's forge, with bituminous coal, which forms, by its baking quality, an oven, or coal roof over the fire, as shown in fig. 287. Thus cheap fuel is made available, and is in fact superior to charcoal. The fagots are formed of 5 or more bars, well supplied with flux, sand, or clay, to prevent decarbonization, and tilted under light trip-hammers, which strike from 300 to 400 blows per minute. The head of such a hammer weighs from 150 to 200 pounds. We have alluded to the effect which hammering has on steel, in preference to rolling, and are justified in entertaining serious doubts of the suitableness of rollers for drawing steel. If no other objection existed to the latter mode of operation, the high heat required for rolling must, in all instances, deteriorate the quality of the steel. The repeated compressions by means of the hammer cannot be supplied by rollers. Soft blistered steel may be rolled.

FIG. 287.

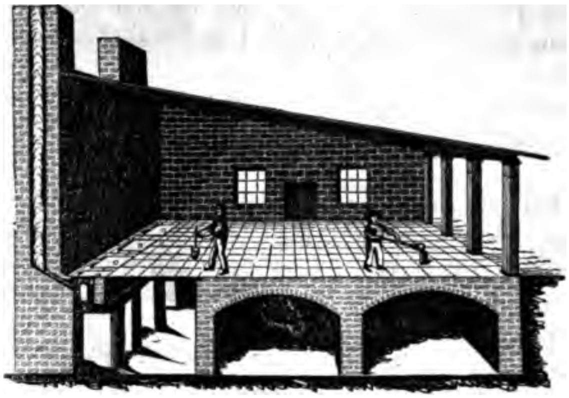


In thus refining steel with care and skill, any quality of welding steel may be produced, cheaper and more perfect than natural steel, to which it is always superior in uniformity. This steel is not quite so uniform as cast-steel, because the joints of the fagots form veins of soft iron. By applying skill and dexterity in welding and drawing, a superior article is manufactured. Slovenly, unskillful workmen succeed very often in metamorphosing steel into soft iron.

Cast-Steel.—Those bars of blistered steel which are highly carbonized, either purposely or accidentally, are broken into small pieces, melted in a crucible, cast in an iron mould, and form cast-steel. The form of the pots is somewhat different from the common one; it is long and narrow, and contains 35 or 40 pounds of metal. Pots are manufactured of fire-clay mixed with coke, or anthracite dust, or plumbago. They are strongly pressed in an iron mould and gently dried, and finally baked, before they are sorted in the furnace. A pot will last for one day, or three heats.

The air furnaces used for melting are similar to those of the brass-founders. The moulds are cast-iron, well polished inside and greased, and form an ingot of from 2½ to 3½ inches square, and 12 or 15 inches in length. In fig. 288 the interior of a casting house is represented. The moulds are set upright so that the fluid metal may run down without touching them.

FIG. 288.



When the furnace for melting is well heated, which is most effectually accomplished by anthracite coal, or hard dense coke, and the crucible also gently, it is inserted upon the foot-piece, and the furnace filled with coal. The fragments of steel are charged by means of a sheet-iron tube, which slides them gently down in it. The steel is covered with a little pounded green glass, and protected against the dropping in of coal by a pot cover of fireclay. Four hours will finish the heat, when a man removes the crucible by means of basket-tongs from the fire, and puts it on the floor. Another workman takes the pot and pours the metal into the mould. Meanwhile the furnace is cleared of clinkers and made ready to receive the hot pot when emptied into the mould.

The ingots thus manufactured are drawn under hammers into the desired forms of bars. A brown-red heat only can be applied to this steel without breaking it; it requires, therefore, a great deal of heating and hammering. This steel cannot be fagoted, and is welded to iron with difficulty. It may be united with wrought-iron in casting it on hot and clean iron, or welding it by means of fluxes, such as borax, or prussiate of potash.

There would be no objection to forming cast-steel of any kind of steel, if melting-pots could be procured, which resist the stronger heat necessary to melt German or shear steel. Heat and flux are both very destructive to the crucible, and more so on the outside than on the inside.

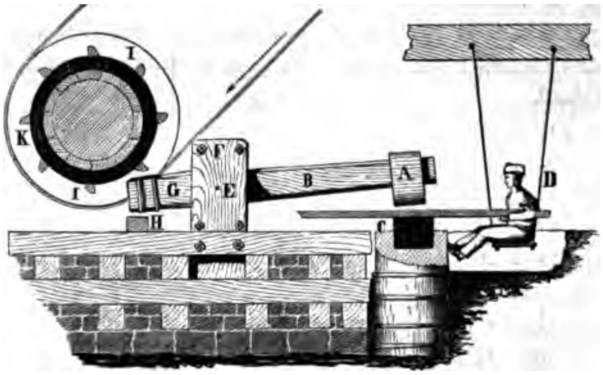
All additions to the steel in the crucible, with a design of improving its quality, are useless, for they will not combine with it. Black manganese is sometimes added, and is said to have a good effect, but it cannot be of any other service than for the removal of some carbon. The same object may be obtained by tempering too highly carbonized steel in black manganese or in peroxide of iron.

Blistered steel gains about a half per cent. on the iron in weight during the process of cementation. Each heat, in refining steel, consumes from 3 to 5 per cent., so that a thrice refined steel has lost 10 or 12 per cent. From 6 to 7 per cent. is generally lost in the first heat.

The high price of good steel, and the apparently simple constitution of it, has been the cause of many experiments and disappointments in compounding it. As a general conclusion in consequence of these trials, we may assert that pure iron well carbonized, is, if not the best, at least as good as any steel. The chief object in making steel is to obtain pure iron, which is more difficult than it at first appears to be. My own experiments, most carefully performed, have convinced me that good steel never can be produced directly from iron ore, all recent demonstrations to the contrary notwithstanding. Steel cannot be made of the best puddled iron; and there appears to be no other successful way but first to make good charcoal bars and convert them, and refine or melt the steel. Silica has so much affinity for iron, and the quantity of it in good steel is so small, that the charcoal forge, for obtaining pure iron, is, and must be considered, with our present knowledge, the only sure means for making a good quality of iron which is suitable for steel. With these remarks ends the chemical metallurgy of iron.

Hammers.—Force-hammers, tilt-hammers, or trip-hammers, are terms indicating the modifications in the form of these machines. Force-hammers weighing 100 pounds, or from 4 to 5 tons, are in use. These modifications are caused by the purpose for which they are designed. The lightest kind of hammers, such as those of 100 or 150 pounds, are used for drawing small iron and small steel rods. For the first purpose, hammers are not much used. Small iron is drawn and finished between rollers. For drawing steel, hammers are indispensable. In fig. 289 a vertical section of a small hammer and its foundation is shown. The hammer-head A, is considered the weight of the hammer, and if it is less than 200 pounds, the hammer strikes at least 300 blows per minute; smaller hammers strike from 400 to 500 blows in that time. In drawing steel rods, the speed is so great that a bar is heated while under the hammer from a black to a brown-red heat, which is visible in daylight. The lift of such a small hammer varies from 3 to 5 or 6 inches, according to the size of the bar. The framework and foundation is always formed of timber; so is the hammer-helve B. Stones or cast-iron are unsuitable materials about a hammer of this kind. The anvil C, is generally

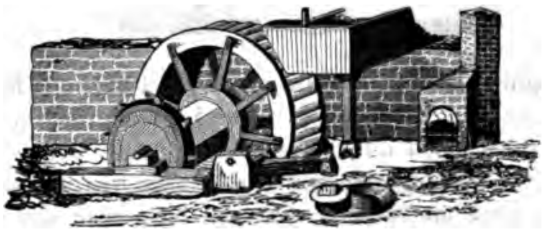
FIG. 289.



almost level with the floor of the forge. This is necessary in order to bring as much of the machine under ground as possible. The hammerman sits on a suspended bench D, and moves his body, and consequently the rod on the anvil, by means of his legs, which he props against the anvil-stock or a plank. On this swinging seat he may move the rod with the greatest rapidity and convenience. The point of suspension, or fulcrum E, is either formed of a collar with two projecting points, held by the standards F, which are of wood in most instances, or it is formed by two journals, as will be shown hereafter. The tail-end of the hammer-helve is provided with an iron plate on its lower side, which is fastened by rings and wedges to the wood. This plate strikes upon a piece of timber G, and drives the hammer-head forcibly down upon the anvil by recoil. The wiper-wheel K, is a heavy cast-iron ring, into which the steel wipers I, are wedged by wooden wedges. The number of these wipers is of course dependent on the number of revolutions of the axis, and the number of strokes of the hammer. If the hammers are small, the wiper-wheel is close to the standards, so that the tail of the hammer extends towards the plumb-line drawn from the centre of the shaft.

The hammer-head is generally of wrought-iron, provided with a well polished cast-steel face; so is the anvil, which is of an equal weight with the hammer. We do not know if good strong cast-iron will answer the purpose for heads, but are certain of its forming good anvils. In this case the cast-iron anvils manufactured in Trenton, N. J., which are provided with fine cast-steel faces, are the best which can be obtained. Cast-iron frame-work requires much repair; besides, hammers thus constructed appear less effective than those suspended in wooden frames. Where water-power is used as the driving force, each hammer is provided with a small water-wheel, and the machine assumes the form shown in fig. 290. In this instance much power is wasted; and

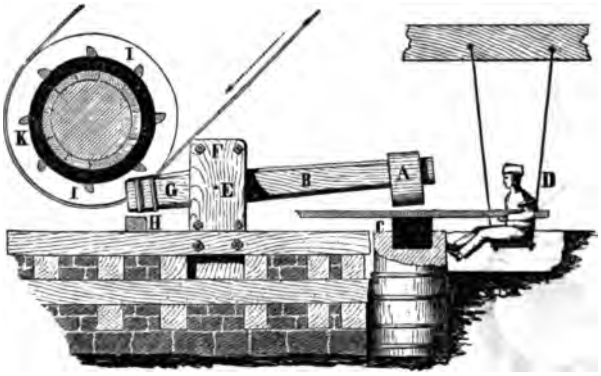
FIG. 290.



in order to save it, or make the best use of water, a large water-wheel is erected on approved principles, and the various hammers in a forge are driven by means of belts. The latter conducts the motion from a counter-shaft of a greater velocity than that of the water-wheel shaft: it drives the wiper-shaft. Belts of this kind are provided with tension rollers, so as to modify the speed of the hammer in a slight degree, without altering the speed of the driving power. When steam-engines are employed as the driving force, a similar arrangement in the machinery is made. This method of driving hammers with an equal, or nearly equal velocity, is suitable for drawing bars of uniform sizes; but when irregular forms are forged, such as tools and hardware generally, where thick or thin parts are at the same time under the hammer, the speed of it must be variable, and at the command of the hammerman. Thick parts require less, thin parts more blows in the same time; and hot metal a less number of strokes than cold metal.

For drawing heavy bars of iron or steel, or forging down balls or blooms, a hammer constructed like that shown in fig. 291 is used, which is of larger size in all its parts, the hammer-head weighing from 250 to 600 pounds, and having a lift of from 12 to 20 inches. It is obvious that a hammer for drawing bars must be constructed differently from one which forges balls into blooms; the first may be lighter, and make a greater number of blows in the same time on the iron than the latter. When a hammer works 80 or 90 strokes per minute, or is of great weight, the reaction caused by the recoil at the tail is destructive to the

FIG. 291.



hammer-frame. In order to obviate, or at least to modify this serious objection to a tilt-hammer, trip or lift hammers have been constructed, at which the lifting cam catches the helve between the head and the fulcrum. The recoil is then produced by a spring-pole, or a piece of timber inserted into the standards, above the fulcrum. The drawing, fig. 292, shows a lift-hammer with cast-iron standards. These may be of wood, but in that case the machine assumes rather an awkward and clumsy appearance, without being superior in effect or durability. In this case cast-iron standards work well, because the reaction upon them is not so severe as with the tilt-hammer. For these large hammers the head and anvil are of cast-iron; and in case the hammer is used for drawing bars, the face is narrowed by casting a relief, T, or a cross, on it.

Fig. 292.

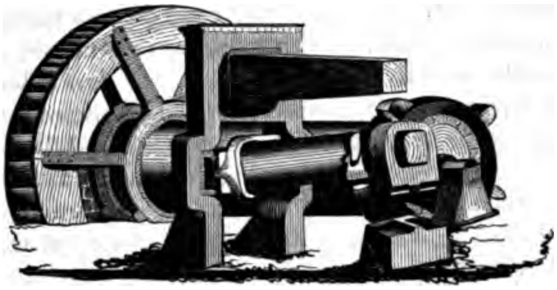


Fig. 293.

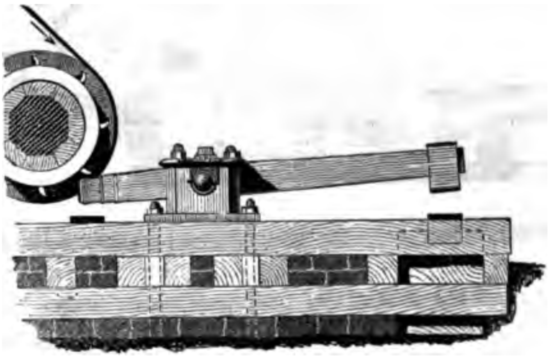
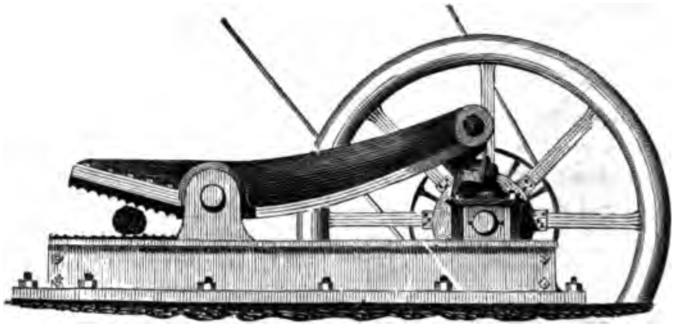


Fig. 293 shows the form of a hammer-machine, which is frequently used. Its construction does not admit of great velocity, and serves chiefly for forging machine-iron. It is also employed in forging blooms. The fulcrum is formed by a cast-iron box, screwed to the helve: its journals rest in plummer-blocks, which are fastened to a strong framework of timber. Small hammers of this construction are used in ore-factories, and in those establishments where no great speed is required.

The heavy English cast-iron hammer is fast losing favor with the iron manufacturers, and there are but few of this kind in use at the present time. For these reasons we do not furnish an illustration of this hammer. They were chiefly used for shingling puddled balls; but as the rotary squeezer performs that operation with little or no expense to the manufacturer, and shingling at the hammer costs at least $1 per ton of iron, these clumsy machines are nearly extinct. A very ingenious machine is the Nasmyth steam hammer; but, besides being expensive, its use is limited to forging blooms, because it works too slow for drawing bars. It is, therefore, of no use in the puddling forge, and is too expensive in the charcoal forge.

Squeezers.—The best machine for forging puddled balls, down to blooms, is the squeezer, of which two distinct kinds are in use, the lever squeezer and the rotary squeezer. A lever squeezer is represented in fig. 294, the construction of which will be understood without explanation.

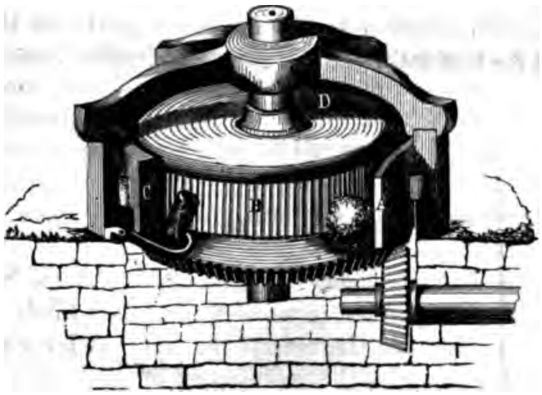
FIG. 294.



All the machine is made of cast iron, the frame of which is firmly screwed down on a solid foundation of stone. The hot balls of iron are inserted between the jaws, which consist of grooved cast-iron plates, and are, by means of a pair of tongs in the hands of a workman, rolled towards the fulcrum. By the upward and downward motion of the upper jaw, which is caused by the revolution of the crank, the size of the ball is diminished, and formed into a round bloom, the ends of which are made solid by upsetting it in the widest part of the jaws.

A more useful one is Burdens' rotary squeezer; it is also a machine constructed entirely of cast-iron. By its action the puddled ball is reduced into a bloom without human assistance. In fig. 295 such a machine is represented. At A, a round puddled ball is thrown in, and the central grooved wheel in revolving about its axis, draws in the ball. The space which is formed by the wheel B, and the fixed inclosure A, is wider at A than at C; the axis of the wheel and that of the inclosure are not the same. At A it is about 12 inches, at C 5 or 6 inches. The ball thus rolled through the machine, appears after about two revolutions of the wheel B, at C, in the form of a round bloom. The upper end is pressed down by the movable cover D; this cover plays loosely on the central shaft, and presses with its weight upon the ends of the bloom. The gearing, or bevelled driving wheels, are generally under the floor of the building.

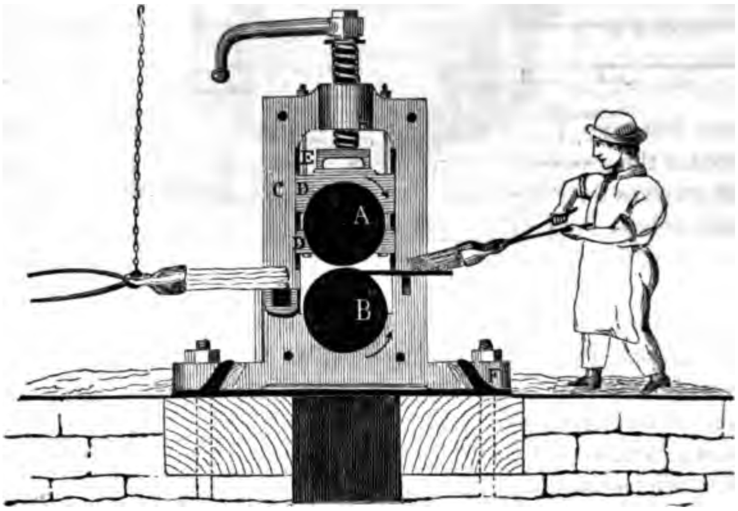
Fig 295.



Squeezers are applicable only to puddled iron, or impure soft charcoal iron. Strong charcoal iron is hard, and a squeezer will not have much effect on it. The rotary squeezer particularly requires hot iron. It is liable to be broken itself by cold or hard iron, or it breaks the balls. Balls which have not been well worked and put together hot, are generally smashed in passing through the machine. It is not true that the use of hammers improves the quality of iron. When it is well worked in the furnace, it is equally as good after having been reduced by the squeezer, as it is by the hammer. The hammer has much influence on steel, but none on iron. The effect which is produced in the charcoal forge on hammered iron is not owing to the effect of the hammer, but to that of repeatedly heating the iron, and preparing it for the hammer. Hammers are necessary for reducing the size of pure, strong iron, for working blooms down to slabs, for heavy sheets, and for forging steel. For such purposes the tilt or trip hammer is the most useful.

Rollers.—In addition to the foregoing machines, rollers are employed for laminating iron. Fig. 296 shows a vertical section

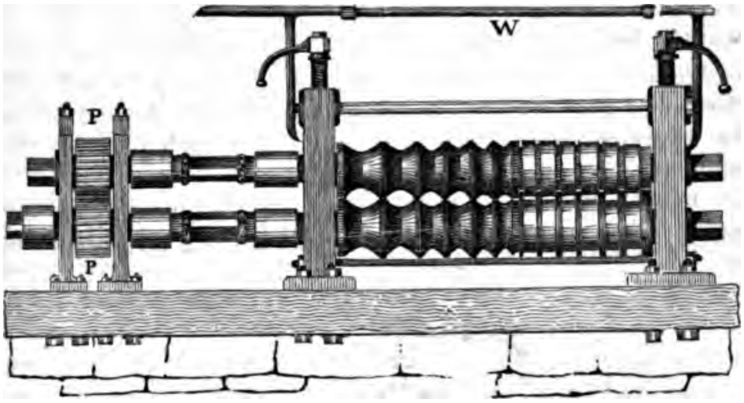
Fig. 296



of a pair of rollers, A B, a view of one standard C, the movable blocks D D, a rider E, and the screw which holds the top roller down, and by means of which the distance between the rollers is adjusted. F is the bed-plate; it is firmly screwed down upon a strong foundation of masonwork, and thus the movable standards are held in it by wooden or iron wedges. This method, however useful when well executed, is not now much in use; the standards are most generally screwed down upon the timbers of the foundation. As these machines are very heavy, and chipping on cast-iron is rather expensive, patterns and castings should be made so perfectly that little work is required on the standards, and those parts belonging to them. The rollers are, of course, always turned round in the turning lathe.

In fig. 297, is shown a pair of roughing rollers; they are, in some instances, 7 or 8 feet long, and 20 inches in diameter, and contain the grooves for square billets down to 2 inches, and also flat grooves for rough bars. This arrangement is objectionable, inasmuch as long rollers are very liable to breakage. We find, therefore, this number of grooves more commonly distributed over two pairs of rollers, of which one is for flat bars, and the other for those which are square, or nearly so. The rollers are driven by two pinions, P P, which are firmly located in a pair of standards, and protected by a screen against accidental injury. Pinions of this kind are very liable to break, and much ingenuity has been shown in their construction, calculated to increase their durability. Nevertheless the simplest form appears to be the best; good, tough, cast-iron, cast in dry sand or loam, and a strong and judicious form of cogs, make as good pinions as any ingenuity can devise. The power of the steam engine is applied at F, and generally drives the lower pinion. Roughing rollers are chiefly used to reduce blooms into bars, and if these are intended to be piled, or fagoted, they are formed into flat bars, from 3 to 5 inches wide, ⅝ to 1 inch in thickness. Iron which is not intended to be refined by piling, is drawn into billets of 1¼ or 1½ inches. These, when reheated, are drawn into small hoops, or small rods. As the heat emitted from the hot iron soon heats the rollers, and as the journals of the rollers ought to be lubricated, a small stream of water is constantly running from a pipe over head to the pans of the

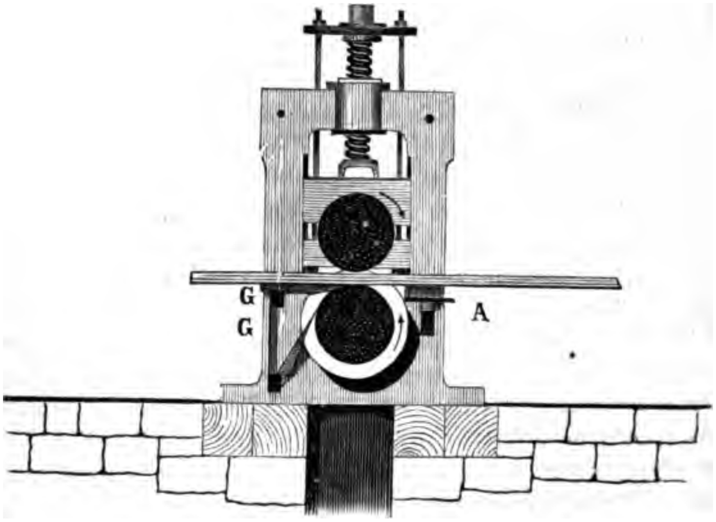
FIG. 297.



journals, which keeps them sufficiently cool to retain grease. The number of revolutions of roughing rollers in a minute is from 30 to 60, according to the size of the rollers and the dexterity of the workmen. As the iron rolled is generally heavy, it requires very little time to pass through; and there is no harm done in working the rollers fast. Where a rotary squeezer, and double puddling furnaces are used, the length of a heat depends on the rollers, and as the shortest time is the most profitable to the work, it is advantageous to run the rollers as fast as circumstances will permit. A rotary squeezer of 4 feet, should make 12 revolutions in a minute, and 16 inches roughing rollers at least 40, although 50 would be better. These rollers belong to the forge; they receive the hot blooms from the squeezer or hammer, and transform them in the same heat into bars. The form of the grooves which receive the blooms is elliptical, of which the short axis is in the vertical direction. The decrease of the grooves is generally, on an average, from 15 to 10, or 15 to 11 in section; for heavy iron, and blooms, it may be from 3 to 2, that is, a bar in the first groove 2 feet long, may be in the next 3 feet long.

In fig. 298 we show a section of a two-rolled train and housing, such as is used in the mill for drawing iron rods of more than an inch in thickness. These do not materially differ from

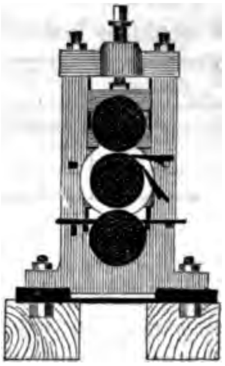
Fig. 298.



the roughing-roller, except in being smaller, about 40 inches long and 14 inches in diameter. They run with a velocity of 80 or 90 revolutions per minute. We observe here the guards G G, which are applied to flat grooves only and at the lower roller, because there the iron is most liable to curl, or run round the roller. The aprons A A, are applied in the same manner as to the rough rollers.

For rolling iron smaller than one inch, round or square, three rollers are put in the standards, one above the other, as shown in fig. 299. These are only 8 inches in diameter, and revolve at least 120 times in a minute. The hot iron bar being rather small in size, cools rapidly and must pass quickly through the rollers; and, in order to lose no time in handing the rod over the top roller, it is passed between that and the middle one, and there receives a drawing as well as below that roller. Small iron, such as inch hoops, half-inch rod, wire rods, are drawn between rollers of 5 or $5\frac{1}{2}$ inches in diameter. These move with great rapidity, making from 300 to 400 revolutions per minute.

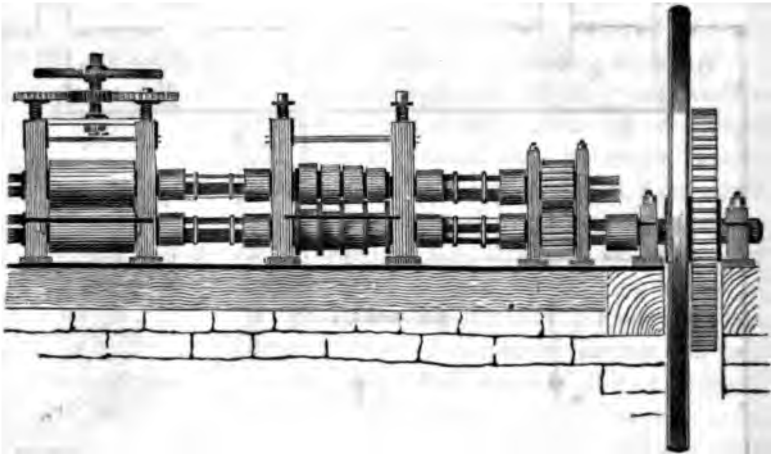
FIG. 299.



The form of grooves in rollers depends, of course, on the form or section required for the finished bar. For square iron, each roller receives a triangular groove; for round iron a semicircular one, and flat iron is formed entirely in the lower or middle roller. Other sections are so arranged that a gradual compression of a square pile or fagot will fill each subsequent groove perfectly. In all instances the grooves are not perfectly of the form which the iron is to receive; the horizontal axis is always larger than the vertical one; because rollers recede a little on passing a rod through. The joint of the rollers also forms a wire-edge, which is to be pressed down by vertical pressure. In some rolling mills it is usual to make the top roller larger in diameter than the bottom one, by which means, it is asserted, curling is prevented; also more straight bars are obtained than in rollers of equal diameter. These precautions are unnecessary; well-turned or smooth rollers, properly guarded, make the best bars, and do not curl the iron.

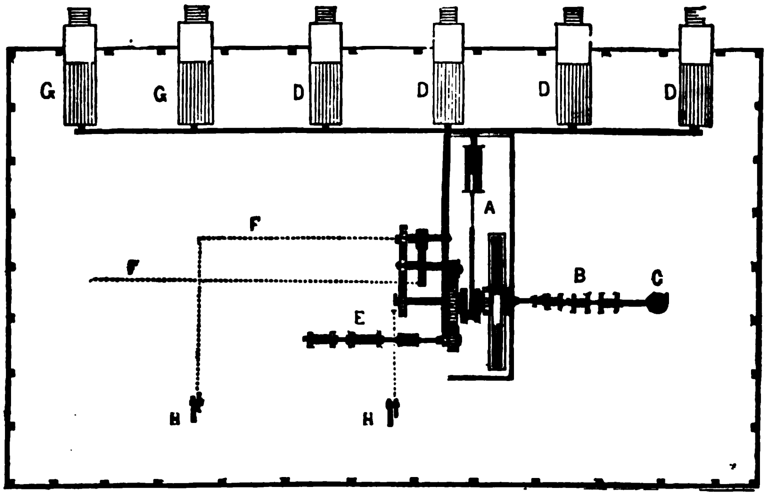
General arrangement of Rollers.—In fig. 300, a train of merchant, or mill-rollers, is shown in elevation. The arrangement is in the usual form. At one end is the master-wheel and the fly-wheel, and two pairs of rollers in a train. These may be either for square, or round, or any other form of iron; or, as represented, they may be used for sheet-iron, or nail plates. The velocity is the same, and by changing the rollers in the standards any form of iron may be manufactured in the same train. On the opposite end of the fly-wheel shaft another train of rollers is generally appended, so that one fly-wheel serves for two, or, in fact, three or four trains of rollers, each of a different velocity from the other. When a steam engine furnishes the driving power, the crank of the engine is generally on the fly-wheel shaft, and one or two master-wheels drive the various trains.

FIG. 300.



The engraving, fig. 301, shows the general arrangement of a rolling mill in plane. The steam engine is placed in the centre of the building, at A, surrounded by a strong railing. At one side of the engine, at B, is the train of roughing rollers for the puddling furnaces. At C there is a rotary squeezer. D D represent puddling furnaces, so arranged that the steam generated at them may be conducted conveniently in the steam pipe S to the engine. The opposite side of the building is occupied by the merchant mill. A train of rollers E, may be either for heavy iron, such as merchant bars and rails, or sheet-iron, &c. This train is nearest to the fly-wheel, because it requires most power. A train of three rollers F, for common bar, may be driven by an underground shaft; either in the same direction as the train E, or located so that more room around the rollers is obtained. A fourth train of small rollers for small iron, hoops, or wire rods, may be appended in the same direction. G G, &c., are reheating furnaces, located in the same range with the puddling furnaces, so as to form a communication of their steam pipes conveniently with those of the puddling furnaces. Shears are placed at H H, which occupy the space between the merchant mill and the forge, so that, in transporting the rough bars from the rough rollers B, to the mill-side, no delay is caused or labor wasted. The opposite side of the mill behind the rollers is an open space not occupied by any machinery; it is entirely devoted to storing iron, shearing, and bundling. There are as many varieties of plans as there are mills in existence, but the one described has been most recently adopted; and it may be considered one of the most perfect and approved plans of distributing machinery and furnaces in a rolling mill.

FIG. 301.



Sheet Rollers.—For the formation of sheets, plain cylindrical rollers are used, such as are represented in fig. 302. Whatever the dimensions of the sheets may be, the principle in these rollers is the same; they differ merely in dimensions, and some minor arrangements. Such rollers as are in use are 6 feet in length, and 20 inches in diameter, or they may be even longer and larger.

Some are 10 or 12 inches in length and of a corresponding diameter, for polishing hoops and small nail plates. For rolling light sheets, or hoops, the top roller is generally loose, and driven by the bottom one, which of course causes a concussion after passing a sheet. In order to modify the shock, which is often the cause of breaking a roller, the top one is balanced by a counterweight, which nearly equalizes its weight. This counter-weight is located below ground, and by means of levers connected with the bear-

FIG. 302.

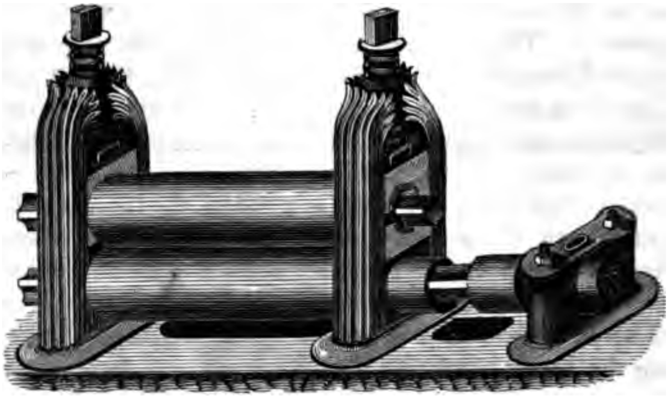
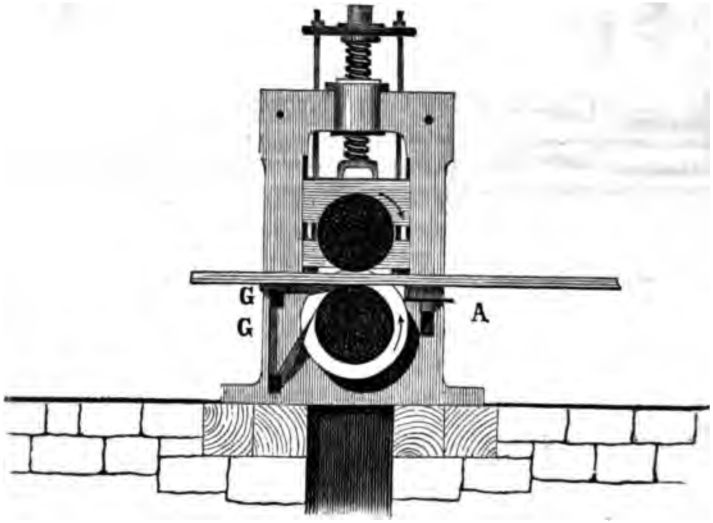
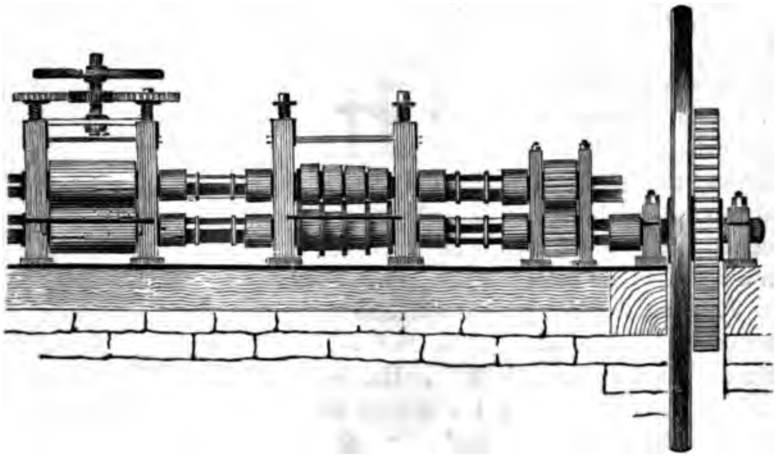


FIG. 303.



ings of the journals. When heavy sheets formed of slabs, which are in many instances 3 or 4 inches thick, are to be rolled, the balance weight is not sufficient to prevent concussions. In these instances, a wooden wedge is passed before and after the slab, and as the rollers work slow, there is little objection to this mode of operation. This requires expert workmen, and causes accidents notwithstanding. Another means by which to work heavy slabs, is to connect the upper roller by pinions with the driving power, like common grooved rollers, and to connect the bearings of the top roller with the standard-screw. A superior arrangement of this kind is shown in fig. 303, where the two screw-bolts connected with the standard-screw lift the roller, and lower it merely by turning the standard-screws. A plate resting on a collar of the latter screw, carries the weight of the roller, and moves up and down with that screw. The means employed for turning the heavy pinch or standard-screws, such as cog-wheels, as shown in fig. 304, are various. But the difficulty in having such machinery so adjusted that each end of the roller will move exactly through the same distance by every motion of the wheels, is so great, that very little use is made of such improvements. A plain cross-wrench on each screw is in most cases preferred by the workmen.

FIG. 304.



Rollers are generally cast of strong No. 2 cast-iron. Gray iron is too soft to resist the pressure of the bars or sheets. White iron is too brittle and hard for common rollers. The durability of these rollers depends on the strength of the cast-iron; the best of its kind is never too good for rollers. As a marketable iron should show a smooth surface, finishing rollers are cast of a close-grained, compact article. It is rather preferable to make rough rollers of a coarse-grained, or coarse-mottled iron. Rollers bite more readily when rough; and as a rough surface does no harm in roughing down the bars, the iron for such rollers may be of a coarse but strong kind. In order to make rollers bite, they are jagged over by means of a chisel—made rough like a rasp. This is an unnecessary labor; when the decrease of the grooves is not too rapid, the rollers bite sufficiently.

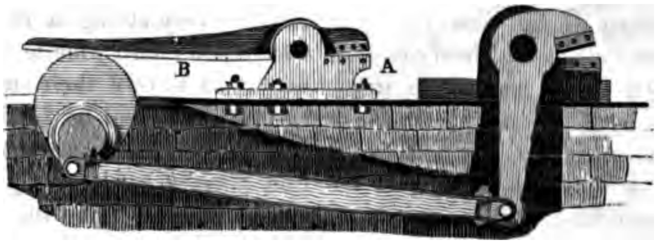
As the surface of rolled metal is a correct fac simile of the surface of the rollers; and as some rods—particularly sheets—require a smooth, even a polished surface, the rollers which are to impart that surface must be smooth or polished. There is no difficulty in polishing any kind of cast-iron roller; but as the pressure of the metal upon the rollers is very strong, it requires hard and close-grained cast-iron to form good hard rollers. Those of this kind are cast in iron chills, so as to cool their surfaces rapidly, which causes the iron to crystallize and be hardened. This operation is based on the same principle as the hardening of steel. Any kind of cast-iron may be hardened by these or similar means; white iron, of course, will form the hardest surface. But as it is too weak for rollers, and gray iron too porous, mottled iron is the only metal which can be used to advantage for hard rollers. A fine-grained, pure, strong iron, melted hot and in a reverberatory furnace, or which is still better, in a hot charcoal blast-furnace, is most suitable for this purpose.

Thin sheets, of a highly polished surface, receive their finishing when nearly cold; the rollers must be, therefore, very strong to resist such a severe pressure. Hot iron may assume a polished surface, but so long as it is red-hot it is liable to oxidation; and the finest face will be covered by a velvety film of oxide in being thus finished.

The strong power applied to rollers, and the necessity of working with sufficient force, makes it a matter of economy to employ the best kinds of cast-iron in rolling-mill machinery. The dimensions of the rollers are limited, and cannot be increased without inconvenience—so are those of the housings, shafts, junction-pinions, junction-shafts, coupling-boxes, plummer blocks, gudgeons, cog-wheels—and, in fact, most parts of the machinery. Breakages cause not only a direct loss in the part broken, but the whole establishment may be deranged, and severe loss incurred by the mere fracture of a junction-shaft or a coupling-box. No roller should be worked without a rider, so that it may break and not injure other parts of the machinery. In a well-managed mill, all breakages occur either in the riders or coupling-boxes.

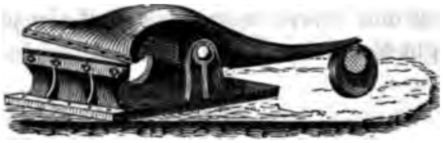
Shears.—The rough bars, as they are furnished by the rollers of the forge, are cut into convenient lengths for piling and subsequent welding. According to the size of finished, or mill-bars, the rough bars are cut into lengths of from 6 inches to 3 feet, and even longer for some kinds of heavy nails or rods. Shears are set in motion by the driving-power, either with a crank, as shown in fig. 305, or by an eccentric wheel at B. This machine is entirely constructed of cast-iron. The cutting edges, which are from 12 to 15 inches long, are of cast-steel, and screwed to the frame by means of bolts which pass through the blades. This kind of shears is used for trimming merchant bars 2 inches thick and smaller, as well as for rough and mill-bars. Heavy bars and rails are trimmed—the fagot-ends cut off—by means of circular saws while the bars are yet red-hot. Such saws are circular sheets $\frac{1}{8}$ of an inch in thickness, about 3 feet in diameter, and they are driven with a velocity of 700 revolutions per minute. They may be either of sheet-iron or steel; if the blade is kept cool while at work, one is as good as the other.

Fig. 305.



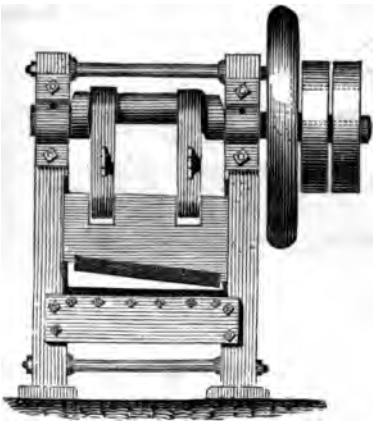
The varying angle of the cutting edges in these shears, which is objectionable—particularly in trimming sheet-iron—has led to the construction of a kind in which this imperfection is avoided. In fig. 306, a simple arrangement is shown, by which a lever-shears is made to cut a length of 2 feet, and more, under an equal angle. The blades are straight, and the distance from them to the fulcrum is short. Shank and shear-block must be of good iron, because they cannot be made very heavy.

Fig. 306.



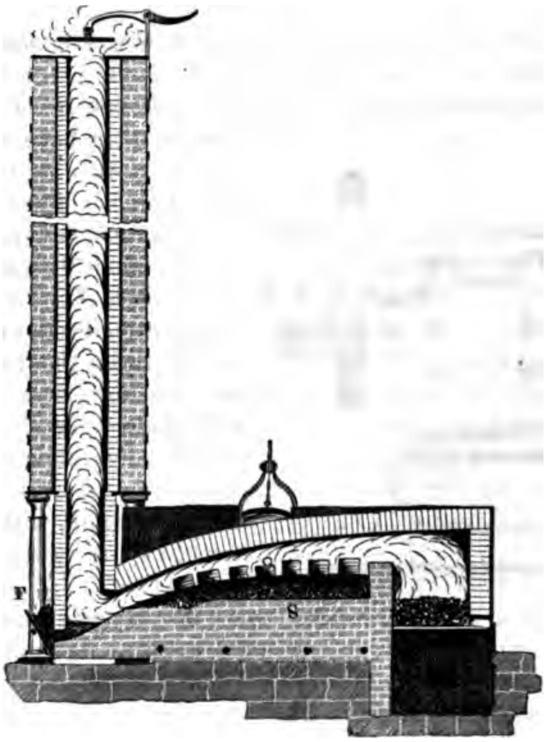
A more perfect form of this kind of shears is shown in fig. 307, which is a front view. The lower blade is firmly fastened to a strong cast-iron frame; and the upper one is set in such a manner as to have a perfectly parallel motion by two cranks located above. The crank-shaft is driven by a belt and pulley, and the motion regulated by a small fly-wheel. This machine may be driven with great speed, making from 100 to 120 cuts per minute. It is extremely well adapted for shearing nail plates, or light sheet-iron. The blades may be extended to almost any length, without interfering with the good effects of the machine.

Fig. 307.



Reheating Furnaces.—Rough bars, or mill-bars, when the iron is twice refined, are fagoted and the piles thus formed exposed to a welding heat in a reverberatory furnace. These furnaces, as shown in fig. 308, are not essentially different from a puddling furnace. The hearth is not often longer than 4 or 5 feet; it slopes rapidly towards the flue, which is necessary in order to preserve it dry and hard. The hearth S is formed of a layer of coarse, pure silicious sand, which is partially renewed two or three times every day. The hot iron in contact with the sand-bottom forms silicate of iron, which flows down into the flue F, and is tapped from it occasionally. A furnace-hearth of 4 feet in width, and equally as long, will reheat about 2 or 3 tons of iron in 12 hours. A furnace 7 feet in width and length, will heat from 7 to 8 tons in equal time. These quantities depend very much on the size of the iron, and the rapidity with which the mill will work it. The degree of heat imparted, depends on the kind of iron; it must be perfectly welded in all cases. Weak iron cannot bear so much heat as strong iron. The amount of iron charged at once, varies with the size of the piles or billets; from 300 weight to one ton forms a charge. The interior of the furnace must be constructed of the best kind of fire-bricks, because it must bear the highest heat produced in any metallurgical operation.

FIG. 308.



The kind of fuel and the mode of heating this furnace, has an important effect on the work which it performs. Wood is the very worst kind of fuel which can be used; the large quantity of water and hydrogen contained in it, notwithstanding it is kiln-dried, causes a heavy loss in iron. With the greatest caution, iron cannot be welded by wood with less than 10 per cent. waste;

12 to 15 per cent. are common. Bituminous coal is most generally used; experience shows that it is not the best fuel, for the waste in iron with it is not often less than 5 per cent., and on an average 8 per cent. Anthracite coal has been found to be the best in the reheating furnace. This may be owing partly to the use of blast; but there is no doubt the chemical composition of the coal has some influence on the result. For we find that in burning bituminous coal in the same furnace, when it is fed by blast, the yield is not so good as with hard coal. Iron may be welded by anthracite coal with an average loss of 3 per cent.; 400 pounds of coal are required to a ton of iron, and fast work by using strong fan-blast. The same amount of iron requires from 500 to half a ton of soft coal, or nearly a cord of kiln-dried wood.

Piles thus welded are taken to the rollers and converted into marketable iron. Fagots for heavy iron, such as rails and heavy bars, must be provided at the top and bottom with mill-bars, so as to resist the stronger heat on the exterior. Mill-bars are those which have been welded once, and drawn into flat bars in the roughing rollers. Iron designed for sheet-iron is also frequently rolled into broad flat mill-bars; these are then merely heated in a stove to a cherry-red heat, and rolled into sheets.

In former pages we have alluded to the welding operation as being a refining process—it is simply so, because the iron is heated, and thereby a further oxidation of its impurities effected; and besides, the iron is forced into longitudinal forms, which cause its crystals and fibres to be elongated. In England, this operation is expressly resorted to for the very purpose of refining; it is not so in this nor in any other country. When iron is carelessly puddled, there is a necessity of refining the bars; but on well worked iron no improvement is perceptible. However, if in this operation iron can be improved, we ought to aim to accomplish it. The only way in which iron thus heated may be made stronger is by oxidation, lamination, and judicious mixture. Oxidation is effected on carbon and on silicon, for which the heat should be gradual, and not higher than is actually necessary for welding the various parts of a fagot together. A plentiful supply of oxygen, or air, is therefore necessary under the grate; and, as a strong draught is required for this, the advantages of high chimneys on reheating furnaces, or of a strong blast, are accounted for. A furnace of this kind has a stack of at least forty feet high, or as much blast as two puddling furnaces. The atmospheric air passing through the grate is only half consumed, and goes unburnt through the furnace: this accounts for the saving of fuel effected by blast, in proportion to that in a furnace with natural draught. The operation must be so conducted that a sufficient degree of heat is produced without having much coal in the grate. Fresh coal is charged when the iron is so far heated that a longer exposure would cause the burning of much of it. From one hour to one hour and a half ought to be the time for a heat; less time or faster work will cause much waste.

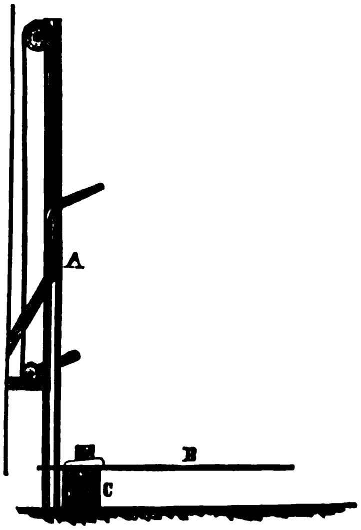
Lamination is a powerful means of improvement; it causes equalization and fibre. It is, therefore, not profitable to make heavy rough bars; nothing is gained by it, but much may be lost. Rough bars, of ⅝ × 3 inches, or ¾ × 3½ inches, ought to form the limits for them, or mill bars which are to be re-heated. Cuts for the formation of fagots should be short, so as to afford a large number in a pile; and in thus causing the piles to be short, a greater number will find room in the reheating furnace. It is a fact too well known by iron-makers, that lamination is of great benefit to quality; still it is sometimes not so much attended to as it ought to be, particularly in the case of coarse iron.

Mixing of iron is, on general principles, advantageous; here it is particularly serviceable. In the best regulated establishments the iron is not so uniform in quality in the rough bars as to make a promiscuous use of them profitable. All rough bars should be tried and classified into two or three kinds, viz., short, middle, and strong iron. The first quality for small iron and thin sheets, the second for common bars, and the third for heavy ones; or, where but one kind of iron—say small rods, or railroad iron, or sheets—are manufactured, the strong iron should be placed in alternate layers with the weak iron. A pile composed of short bars will invariably make short iron; strong rough bars may form good iron, but a well regulated mixture of weak and strong iron will produce the best bars or sheets.

In fig. 309 we represent a machine for breaking rough bars, which is used in one of the best mills. A cast-iron drop A, is raised about 15 or 16 feet, and, on being unlocked, falls down upon the fastened bar B, and either will break or bend it. The drop is about 100 lbs. in weight; the bar is wedged upon a block C, of cast iron.

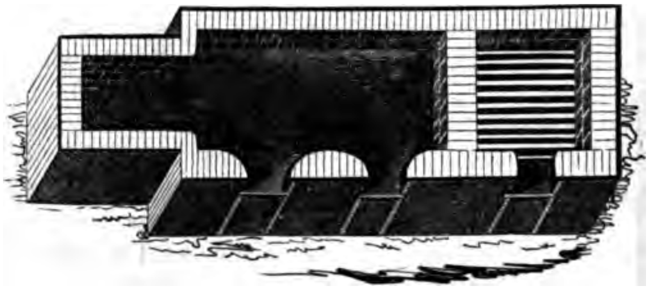
The manner in which iron is fagoted has thus a decided influence on the quality of the bars manufactured. The mode of reheating it is another means of improvement. If it must be considered profitable to reheat puddled or impure iron slowly, it is not so with strong or pure iron, which must be heated quickly. A long exposure to heat will cause it to be brittle when hot, and rotten when cold. Strong iron requires a quick heat and rollers that move fast. Cold, short puddled iron forms good hoops, and also a good quality of small rods; it is better suited for this purpose than strong iron. But short iron is not good for slit rods; it is also inferior for common and heavy bar. Weak iron ought to be used for those kinds of merchantable articles which are subjected, in the course of their manufacture, to repeated reheating and drawing, such as all small iron and their sheets. Strong iron should be used for heavy bars and heavy sheets, nail-plates, and slit iron. Of the latter article, and the mode of its manufacture, we have omitted to speak, because but little is manufactured and used. Small rods are preferable to slit iron; and, for these, cold short boiled iron is a first-rate material.

FIG. 309.



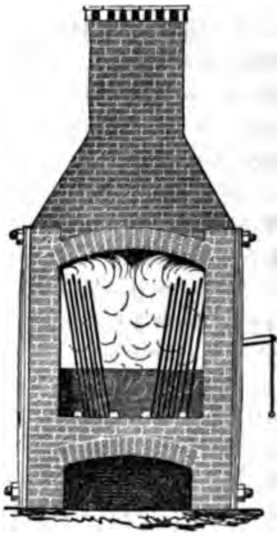
Stoves.—When iron has been welded, and is sound throughout its body, it requires merely a high cherry-red heat for all subsequent operations. As in reheating, so here, a weak puddled iron, or weak iron, generally requires a slow heat; and strong or charcoal iron, a quick heat in the stove. For some kinds of work, such as small iron, light sheets, and hoops, a common reheating furnace is used, which is often of considerable size, and provided with two doors, as shown in fig. 310. The hearth, in this case, is about 8 feet long and 5 feet wide. The fire-bridge about 8 inches high, and the roof 15 inches; while, in common reheating furnaces, the roof is not often more than 12 inches, and the fire-bridge 4 inches high. A strong draught is not required, but the application of blast is very advantageous. In fact, no reheating furnace, or stove of any kind, should be worked without blast, even if its application at puddling furnaces is disregarded. Any common reheating furnace may be used as a stove when its flue is contracted. The hearth of a reheating furnace forms a flue from the fire-bridge to the stack. This flue may be, for reheating, as wide as the space over the fire-bridge. If the furnace is to be used as a stove, the hearth near the stack is raised by sand, in order to retain the heat on it. A reheating furnace is made to work faster or slower by widening or narrowing the flue. This principle is applied at all reverberatory furnaces. The enclosure, doors, grate, stack, and other arrangements at a reheating furnace, are similar to those of a puddling furnace.

FIG. 310.



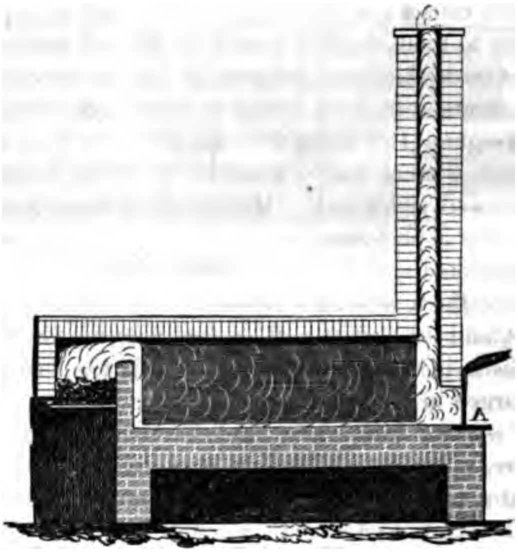
When sheets have become of such a size that a reheating furnace cannot be used for heating them again, a stove with a high roof is employed, in which they may be set edgeways. The cut, fig. 311, shows a vertical cross section of a stove for sheets. The height of the arch from the hearth must be some inches more than the width of the sheets, and the length of the stove a little more than their greatest length. A stove is a mere annealing apparatus; the heat applied is a brown red, and the flame draws slowly along the roof, so as to touch the sheets as little as possible. They are frequently turned while in the stove, in order to impart the heat uniformly. As this operation is also an act of annealing, it ought to be performed slowly, and all the

FIG. 311.



oxygen which passes through the fuel should be consumed. A large grate and sluggish draught is therefore advantageous. In some instances the door A, which is a plain cast-iron plate, sliding up

Fig. 312.



and down, is within the chimney, where all the smoke escapes. The plan which is represented affords advantages for faster work. Its operation is very simple. When the furnace is heated thoroughly to a high red heat, and sufficiently charged with fuel, the register of the chimney is shut, the sheets are charged, and the door is shut. The iron is thus slowly heated, and when brown-hot at the top, the sheets are turned, and their lower edge exposed to the stronger heat near the roof.

Heavy sheets, such as boiler plates, are generally rolled down at a single heat from the furnace. This stove is used only for those sheets which cannot be reduced in one heat, and require annealing. Two, three, or more of these sheets are passed through the rollers together; and, as it may happen that they will adhere together when heated too strongly, an excessive heat should not be imparted to them. They must be also uniformly heated, because the hottest parts, being softer, will stretch more on being rolled than the cold parts. In order to prevent their adhesion together, and to equalize the heat, they are separated, and their surfaces of contact changed after having twice passed between the rollers.

Particular attention should be paid to heating sheets. If oxygen or vapors of water issue from the fire, or atmospheric air finds access to the interior of the stove, the sheets form crusts of oxide, which causes a serious loss of iron; and, as this oxide adheres firmly to them, it gives them a rough and uncouth appearance. Not more than one per cent. of loss in iron should occur in rolling sheets, even if the scraps or trimmings are not deducted from the weight. Hot short iron should never be used for thin sheets—there is much loss in trimming it. Cold short iron forms good sheets, and yields well. Most kinds of sheet iron are finally annealed; this is performed in the stove, which, after it has been thoroughly heated and the grate well supplied with coal, is closely charged with them, when all doors are shut, so that no air may find access, and it is left to cool gradually. In order to lose little time and heat in this operation, the stove is filled in the evening and discharged in the morning.

Cost of making Iron.—The expenses incurred in manufacturing iron are, as a matter of course, very variable, and the following estimates are by no means generally applicable. Iron ore is obtained in some localities, at 75 cents a ton, of 2240 pounds; at other establishments the same quantity costs $4, and even a higher price is paid. The cost of ore, until it reaches the top of the blast-furnace, ought to be calculated, and for a quantity sufficient to smelt a ton of iron, because some ores are attended with considerable expense in the yard for roasting and cleaning. And as the quality of ore thus brought to the top has a decided influence on the cost of smelting, it follows that refractory ores are not so cheap to the smelter, at the same price, as fusible ores. Hematites and all hydrated oxides work cheaper in the furnace; the next are the native oxides, the roasted oxides, the carbonates, magnetic oxides, impure carbonates and silicates. At the same prices a quantity of hematite ore, which is sufficient for smelting a ton of iron, is cheaper to the smelter than a similar amount of magnetic or roasted argillaceous ore. The facilities for smelting some kinds of ore so much exceed those for others, that a marked difference in price is no objection to using the most expensive kind. While one kind of ore, in a sufficient quantity for smelting a ton of iron, is expensive at $3, another kind may be cheap at $8 or $10. But if, in these instances, the nominally cheap ore is mixed with the other, the mixture is, in almost all instances, found to be still cheaper. Our ore-beds are generally extensive and heavy; ore is, therefore, generally cheap, and it is not uncommon to see sufficient for a ton of iron brought to the smelt-works for $1; yet some furnaces in the New England States pay as high as $10 for the ore for a ton of iron. Here is, therefore, a great difference in the cost of raw material; and there is no doubt, if those works which can obtain cheap ore use the same amount of skill and industry as those which work refractory or high-priced ore, they must have great advantage over the latter.

The amount of flux, which is in almost all cases limestone, varies from half a ton to 1½ tons to a ton of iron. Charcoal furnaces and hot-blast do not often use more than half a ton; anthracite or coke furnaces consume the largest amount when blowing with cold-blast, and one ton when using hot-blast. A ton of limestone is, in most instances, furnished to the furnace at 60 cents, and from that to $1. The breaking of it causes an additional expense of from 40 to 50 cents.

Fuel varies in price and quality considerably. In the State of New York we see a ton of pig-iron smelted by the use of 130 bushels of charcoal; in Pennsylania it is not done often with less than 180 bushels; and in the Western States 200 bushels and more is the average. The price paid for a bushel of charcoal at the top of a furnace, varies from 5 to 8 cents. One ton and three-quarters of anthracite coal for a ton of pig-iron may be considered the lowest estimate, and two tons the largest; and as the price of anthracite coal at the works is from $2 25 to $3 50, the expenses for fuel may be easily estimated. In case bituminous raw coal is used in smelting, an amount equal to that of anthracite is necessary; and as that coal may be bought at 40 or 50 cents a ton in some of the localities of the Western coalfields, the advantages of that region for manufacturing iron are obvious. An equal amount of coke to anthracite is used for a ton of pig-iron; and as not more than 60 per cent. of coke is often obtained from stone coal, and as the labor for charring the coal must be added, the cost of coke iron is readily computed. The labor in the yard and at the blast-furnace, costs nearly two dollars—this is at charcoal-furnaces which use raw mine; the roasting of ore costs about $1 more. At an anthracite furnace these expenses are about the same, or rather lower. Smelting a ton of coke iron, when the coking is included, never costs less than $3, and generally nearly

$4. The general expenses—such as management, blast, and interest on capital—may be set down at $3 per ton of iron.

The manufacture of a ton of blooms directly from the ore, requires from 2⅓ to 3 tons of rich ore, and from 200 to 300 bushels of charcoal; the labor will cost $8, and the general expenses will be $2.

A ton of charcoal blooms takes from 1⅛ to 1⅓ tons of pig-iron, 150 to 250 bushels of coal; the cost of labor is from $6 to $10, and general expenses about $3. Drawing the blooms into bars causes an additional expense of about $5 per ton.

Iron may be refined in a run-out fire with a loss of 8 or 10 per cent., the use of half a ton of coke or 60 bushels of charcoal, and at an expense of $1 for labor, and $1 for general expenses.

Puddling is done at $3 to $4 50 for labor per ton of iron, with a waste of 3 to 15 per cent. of iron, and the consumption of 1400 pounds of coal. When the balls are shingled by a hammer, the hammer-man receives $1 per ton. Drawing of the blooms into rough bars, costs about 40 cents per ton.

In reheating from 3 to 10 per cent. of iron is burned, 400 pounds to one half ton of coal is used, and 50 cents to $1 in wages is paid to the furnace-men per ton of rolled iron. The drawing at the rollers costs in wages about $1 for heavy bar, $2 for common bar, and from that to $5 for small iron. These latter statements are not generally exact; we find the sums paid both lower and higher at different places. The expense of rolling sheet-iron cannot hardly be estimated; but $10 for wages and fuel per ton may be near the amount. The general expenses in a rolling-mill are high; because of the extensive machinery used, heavy capital employed, and the vicissitudes of trade. It may not be too high if we assume $6 as an average expense per ton, although it is in most instances higher.

The amount of iron produced in the United States is estimated at 800,000 tons per annum. The labor of about 250,000 persons is required to manufacture it. The consumption of iron in the Union is about 1,100,000 tons yearly—300,000 tons of which are imported from Europe. One-third of all the iron manufactured in the United States, is produced in the State of Pennsylvania. The establishments there are capable of producing 500,000 tons per annum.

Nickel.—This metal is found in only a few places. In these respects, and in regard to its weak affinity for oxygen, it belongs to the class of precious metals. When pure it is almost as white as silver, although rather inclined to a gray color; it is ductile and malleable, either when hot or cold. In its pure state, also, it is as refractory as any iron or manganese, and requires as strong heat for melting as these metals. Its specific gravity is 8·27 to 8·66. It is similar to iron in respect to magnetism, and resembles steel more than pure iron by retaining a sensitiveness to the magnetic current. It has a capacity for carbon similar to iron, and in many particulars resembles the latter metal.

Ores of Nickel.—This metal occurs native in meteoric iron, but in that form it is of no practical interest. In most instances nickel is combined with arsenic, iron, copper, antimony, sulphur, and oxygen. A large number of minerals contain nickel; but the only practically useful ore is the following:

Copper-Nickel.—This is a heavy mineral, its sp. gr. is 7·3 to 7·6; it is of a metallic lustre, and possesses considerable hardness; its color is copper-red, displaying all the hues of the rainbow—most frequently the red color inclines to brown or gray. The mineral is brittle, and its powder is dark-brown. The composition of the pure ore is—nickel 44, and arsenic 56; but it never occurs in that form. Copper-nickel always contains iron, lead, sulphur, and antimony.

All the nickel ores are found in veins in the old rocks, associated principally with cobalt. In fact the cobalt ores are the chief source for the manufacture of nickel. Copper-nickel is generally found in cobalt mines—as in those at Chatham, Conn. Nickel ore occurs in Lancaster county, Pa., and in a variety of minerals in Missouri. The chrome mines of Maryland and Pennsylvania furnish it. As a general rule nickel occurs in silver, copper, or lead mines, in cobalt and chrome mines—particularly in those which are located in gneiss, mica-slate, serpentine, and similar rocks.

Cobalt-Speise.—Wherever cobalt-glass is manufactured, a substance is found at the bottom of the smelting-pots—called, by the Germans, cobalt-speise—which contains large quantities of nickel. This substance is the material from which the metal nickel is extracted, and may be considered the only valuable ore. Cobalt is sooner oxidized than nickel; and if in smelting smalte all the cobalt is not oxidized, we are certain to obtain all the nickel in the speise. The residue thus obtained from smelting smalte is, as a matter of course, not uniform in composition; it contains a variety of other metals, together with arsenic and sulphur. An assay of a German specimen of cobalt-speise contained—nickel 49, cobalt 3·2, copper 1·6, arsenic 37·8, sulphur 7·8, and some antimony; also sand and other impurities in very small quantities. It contains also iron and manganese, and, of course, the precious metals in case they are contained in the crude cobalt ore. The appearance of this artificial ore is similar to the natural copper nickel; it is crystallized in prisms, and shows the red variegated colors.

Alloys of Nickel.—This metal is hardly employed in its pure state, and is known in commerce as an alloy only. Nickel renders other metals harder and brittle; its alloys possess a greater or less degree of whiteness, and are known by a variety of names. Argentan, pack-fong, German silver, electrum, British plate, and others, are alloys of nickel. An alloy of copper and nickel may be made as white as silver; but as nickel is rather expensive, zinc and iron are substituted for it, which in small quantities are not injurious to the alloy. In large quantities, iron or zinc render the compound brittle.

Argentan is the most common alloy of nickel. It is generally known as German silver. The composition of this metal varies almost indefinitely; no other branch of alloys has received so much attention. The oldest alloy of this kind known among the Germans, is the white copper of Suhl. It is a compound of 88 copper, 8·75 nickel, and 1·75 iron. Chinese pack-fong contains more or less zinc, and is brittle; 43·8 copper, 15·6 nickel, and 40·6 zinc, is one of their alloys. Pack-fong is very irregular, and frequently contains besides these metals, iron, antimony, and other substances. A very strong, sonorous metal is formed of 50 copper, 18·7 nickel, and 31·3 zinc; the specific gravity of which is 8·55. French maillechort, a very ductile alloy, receives a fine polish and may be advantageously gilded; it is composed of copper 65, nickel 16·8, zinc 13, and iron 3·4. By increasing the amount of nickel to 20 or 25, copper to 50 or 60, and reducing the zinc to 20, a very strong malleable metal is formed, the malleability of which is increased by adding 2 or 3 per cent. of lead. Copper 60, nickel 20, zinc 20, forms good table-knives, forks, and spoons; 57 copper, 20 nickel, 20 zinc, 3 lead, is a metal suitable for ornamental objects. It may be stamped and soldered.

The qualities of argentan vary with the proportions of the various metals, and the purity of the alloy; that is, with the absence of arsenic, sulphur, carbon, and similar matter. A little iron does no harm; it increases the color and brilliancy of the alloy, but more than 3 per cent. causes brittleness, and hardness. The presence of arsenic renders the alloy extremely brittle and unfit for any use. Lead impairs its lustre and strength.

We find it to be difficult, when forming the alloy, to combine a definite proportion of zinc with the compound of nickel and copper previously prepared. In fusing the three metals together there is always a loss of zinc by volatilization, which may be lessened by placing it beneath the copper in the crucible. The best method is to melt the zinc first at a low heat, by which it does not evaporate, and then add the copper, or simultaneously copper and nickel in thin strips or spangles. These metals will gradually dissolve in the fluid zinc, and the heat may be raised as their fluidity increases. In this instance, as in all others of forming alloys, it is profitable to mix the oxides of the various metals together, and reduce them under the protection of a suitable flux. The metal nickel can be produced only from pure oxide of nickel; and, as purity of the alloy is essential to good quality, the common commercial zinc is not sufficiently pure for forming argentan. Copper cannot well be used in the form of oxide, but small scales, or wire-scraps, will serve eqnally as well. The stampwork of the Lake Superior copper ores, the red oxide of zinc of New Jersey and pure oxide of nickel mixed in proper proportions and reduced in a clay crucible, ought to form a superior argentan.

Use of Nickel Alloys.—German silver is extensively used for the manufacture of spoons, forks, and kitchen utensils. Vessels which are formed of this metal are far less liable to prove injurious to health than those formed of copper, brass, bronze, or even glazed earthen-ware; argentan should not be used in vinegar, or for preserving fruit; the utmost cleanliness is necessary in order to avoid poisonous effects. If it is clean, not the slightest danger may be apprehended from its use. Some kinds of this alloy are extremely tenacious and form elastic springs like steel. It appears that nickel imparts to most of the metallic alloys, particularly to those of copper, a higher degree of strength than they possess without its presence.

Manufacture of Nickel.—Since it is an object of importance to employ pure metal in forming the alloy, the attention of the smelter must be directed to obtaining a pure ore. The nickel ores, either the natural or artificial ores, are roasted in a reverberatory furnace, so as to oxidize and evaporate all those substances, which are liable to volatilization in a red heat. The ore is, for this purpose, crushed to a coarse powder, washed like zinc or lead ores, and roasted in a furnace similar to that used for roasting zinc ores, which is represented in figs. 313 and 314. If the ore contains much arsenic, which is generally the case, it is like cobalt ore, and the arsenic is gathered in condensing chambers. The ore is oxidized to the highest degree, and all arsenic must be perfectly driven off, by the aid of charcoal powder. It is then mixed with three parts of sulphur and one part of potash, and the whole melted in a crucible at a very low heat. This forms a black slag, which is edulcorated with water, and leaves a powder of metallic lustre, which is sulphuret of nickel and free from arsenic. If arsenic remains in the ore after roasting, it is in the potash solution with some of the sulphur. If there is much, the amount of potash must be increased; it is often used in equal parts with sulphur. In melting ore, potash, and sulphur together,

Fig. 313.

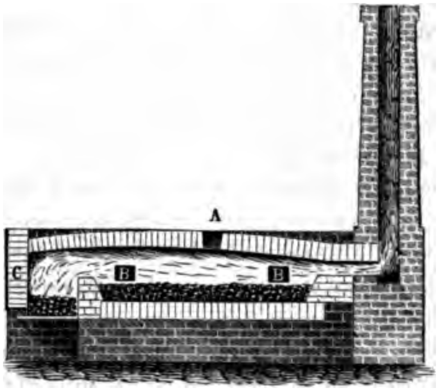
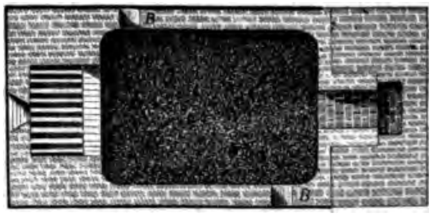


Fig. 314.



the pot must be large and the heat low, or the mass is liable to boil over.

The sulphuret of nickel, which remains after dissolving and driving off all other substances, is repeatedly washed with pure water; this will extract all substances which may be soluble in it. If the crystals formed in melting are large, they are liable to be impure, and must be crushed and washed very often; a low heat will form small grains, while a high heat forms large crystals; if for no other, it is necessary for these reasons to melt the substances together at a low heat. The pure sulphuret is then dissolved in nitric, or, cheaper, in sulphuric acid, to which a little nitric acid or aqua-fortis is gradually added. When the operation with the potash has been well performed the solution of nickel—salt—is pure, but if the heat in melting has been too high, or if sufficient potash or sulphur has not been used, the solution contains arsenic, from which it must be freed by remelting in potash and sulphur, before the sulphuret can be dissolved.

The solution thus obtained with the acids may contain iron and other metals, which must be removed from it. If no free nitric acid is present, the solution is set to boiling in a pan of sheet lead, and carbonate of potash is added in small portions. This throws down oxide of iron. In order to succeed well, all the metals in the solution should be peroxides; these may be rendered so, if they are not, by the addition of saltpetre and sulphuric acid. The peroxide of iron falls when the fluid is yet acid, and all of it may be removed by means of potash before any other metal is precipitated. Copper is then removed by conducting sulphuretted hydrogen into the solution, which precipitates sulphuret of copper. There cannot afterwards remain any thing in solution, except nickel and cobalt; the separation of which is somewhat laborious. The mode by which it is done depends on the predominance of either one or the other; we shall describe the extreme of either case.

When nickel predominates in the solution, it is mixed with caustic ammonia until all the precipitated oxides have been redissolved. The blue solution is now diluted with boiled water. It is not necessary that the water should be hot, but it ought to have been boiled in order to remove the atmospheric air which water generally contains. The diluted solution is preserved in an air-tight vessel, after having been mixed with caustic potash so as to form a green precipitate, and cause the disappearance of the blue color of the solution. It forms slowly a green sediment; and a red or reddish solution, with more or less cobalt, remains. When perfectly clear this is drawn off by means of a syphon, and the sediment, which is green oxide of nickel, is repeatedly washed with distilled water for the removal of the adhering solution of cobalt. The solution contains much cobalt, when of a light-red color. A dark color indicates the presence of nickel, or superoxide of cobalt. In order to prevent the formation of the latter, water freed from air and closed vessels are used in the operation; for superoxide of cobalt would fall as a black powder along with the green oxide of nickel. When the precipitate of green oxide of nickel dissolves entirely in an acid without leaving any residuum, it is an indication of its purity.

When the quantity of cobalt is greatest in the precipitate obtained from the first solution, it is cheaper to precipitate the oxides from the solution by carbonate of soda or potash and redissolve the precipitate in oxalic acid, which forms a powder of oxalates, insoluble in an excess of the acid. The oxalate is washed or freed from acid by filtration, and dissolved in caustic ammonia. By evaporating or heating this solution, the ammonia is driven off, and the oxalate of nickel falls as a green powder, while the oxalate of cobalt remains in the red solution. The nickel thus obtained is not pure, and ought to be subjected to the first method of treatment in case a metal free from cobalt is wanted.

This process of manufacturing nickel, or the formation of pure oxide of nickel, is very much of a chemical character, and has little similarity with metallurgical operations. The reduction of the oxide of nickel to metal is very simple; because the metal has but little affinity for oxygen, particularly when hot. In manufacturing nickel, this metal should always predominate in the ore; because it is expensive to remove other metals from it, particularly cobalt.

The smelting of the oxide of nickel with charcoal in a crucible, may be accomplished in a strong fire; but the metal retains carbon in this case, and consequently it is brittle and spongy. For obtaining pure metal, the oxide is saturated with oxalic acid, ignited by a strong heat in a good crucible. The spongy metal thus obtained is broken, or pulverized, and reheated again under cover of pure soda glass. In the last melting, if the heat applied is as high as the best crucible will bear, the metal is obtained in grains of the size of peas. Nickel has so little affinity for oxygen, that the presence of a little carbon is sufficient to form metal; and even without carbon, metal is produced from the oxide in the high heat of a good air-furnace.

Nickel is very refractory; and as the metal is not used in its pure form, it is not necessary to produce it in that condition. Alloys are easily and correctly formed by mixing the oxides of the various metals, and reducing them together. As the oxide of zinc, and perhaps a little iron and some other metals in small quantities are required only to form nickel alloys; and as zinc will evaporate from nickel, it is the better plan to melt metallic copper and oxide of nickel together, and add pure brass to the melted mass. By charging the latter metal strongly with zinc, the necessary amount of it is easily incorporated with the alloy.

Nickel has been, and is still manufactured near Philadelphia; partly from Pennsylvania ores, but chiefly from those obtained in Missouri. We are not acquainted with the extent of its manufacture.

Cobalt.—This metal is similar to nickel; its alloys are more brittle. Its specific gravity is 8·4 to 8·5. Its color is reddish-gray, and the metal has but little lustre. It is slightly malleable, and extremely sensitive to impurities. Cobalt is as refractory as nickel or iron, and requires good crucibles and a strong fire to melt it. It resists oxygen like steel, but not so well as nickel. At a white heat it burns with a red flame.

Ores of Cobalt:—These are chiefly the arseniurets, of which cobalt-glance and cobalt-pyrites are the most valuable. The first kind of ore is not known at present in the United States, at least not in such quantities as to be of practical use. Sulphuret of cobalt or cobalt-pyrites, occurs in Missouri. Cobalt-manganese—an oxide of cobalt—is obtained from the La Motte mine of the same State. Cobalt-glance is composed, on the average, of 33·1 cobalt, 43·4 arsenic, 20 sulphur, and some iron. Cobalt-pyrites is composed of 43 to 53 of cobalt, and 39 to 43 sulphur.

In the cobalt mine, at Chatham, Conn., smaltine, or tin-white cobalt, a binarsiniet of cobalt, is found. It occurs in veins traversing gneiss, and is associated with nickel ores. This species of cobalt ore contains a large amount of arsenic—on the average, 70 per cent., about 20 per cent. of cobalt, and the remainder is iron, copper, or nickel.

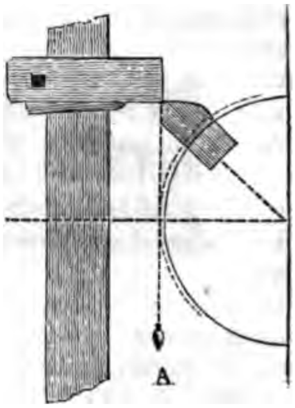
The presence of iron, copper, and particularly nickel, in cobalt ores, is very annoying to the miner; these metals are injurious to the blue color which is obtained from cobalt.

Alloys of Cobalt.—This metal combines with most others readily, but its alloys are not much known, and less in use. It has, like nickel, a strong affinity for arsenic, and most of its combinations resemble those of iron in their properties.

Smalt, Azure, Zaffre.—The only use of cobalt is in its oxide, which, when melted with alumina or silex, forms a fine blue color, which is extensively used; smalt, or the pure oxide, is used for coloring and painting glass, porcelain, and crockery, a blue color. It is employed as cobalt glass in oil painting, and, in fact, serves as a fine, permanent blue color in all instances where such a color is needed. Oxide of cobalt forms a green color when heated with oxide of zinc; but as this compound is expensive, it is not in use.

Manufacture of Smalt.—As the presence of iron or nickel is very injurious to the blue color derived from oxide of cobalt, the ores are picked and separated into two classes, pure and impure ore. The rich ores are stamped and washed, in order to remove earthy impurities; and, as the ore is heavy, there is no difficulty in succeeding in this perfectly. The operation of crushing is performed in a machine similar to that represented in fig. 315. The ore thus purified is placed on the hearth of a reverberatory furnace and roasted for several hours, to remove all the arsenic and sulphur. The latter escapes, in the form of sulphurous acid gas, through the chimney, into the atmosphere; the former is condensed, as arsenious acid, in the poison chamber. Both arsenic and sulphur adhere firmly to cobalt, and when a pure article of oxide is required, the operation of roasting is tedious. The last traces of arsenic are never entirely removed. A small amount of this impurity does no harm in the subsequent smelting operation, because so much free oxygen is always in the ingredients with which the cobalt is melted, that most of the arsenic is removed by its assistance.

Fig. 315.



Those ores which contain much nickel or other metals, are roasted only in a certain degree. This ought to be performed with skill. In heating the crushed and washed ore gently, but uniformly, a portion only of the sulphur and arsenic is evaporated; the remaining portions oxidize with the metals in the atmosphere. Nickel has more affinity for arsenic than other metals, and when the partially-roasted ore is exposed to slow oxidation in the air, all other substances, sulphur not excepted, become oxidized, and may be removed by water. Nickel will resist the effects of air for a long time, but it would finally be also oxidized, if not removed before that is effected. From six to twelve months' exposure will not oxidize the arseniuret of nickel. To have good success in this operation, it is necessary to heat the ore uniformly, so that each particle may be deprived of a little arsenic or sulphur. The leading principle in this operation is, that when pyrites is deprived of a small amount of sulphur or arsenic, its decomposition goes on rapidly and perfectly in the atmosphere. When, therefore, small grains or particles of the natural pyrites are mixed with the mass, they will not be oxidized with those which have been heated, and consequently the result of the operation is imperfect.

Fig. 316 I.

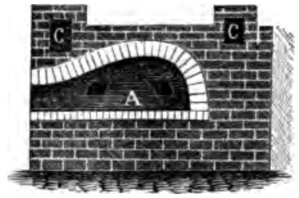


Fig. 316 II.

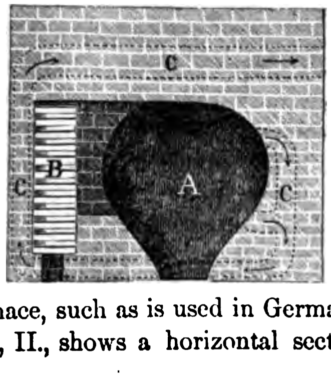
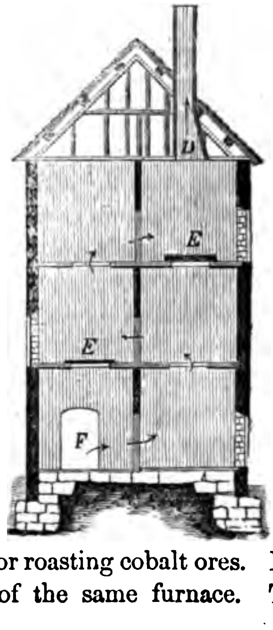


Fig. 317.



In fig. 316, I., is shown a vertical section of a reverberatory furnace, such as is used in Germany for roasting cobalt ores. Fig. 316, II., shows a horizontal section of the same furnace. The hearth A, and the roof are formed of firebrick. At B is the fire-place. C C C are channels for carrying off the gases from the hearth and conducting them to the poison chambers in a building represented in fig. 317. The arrows in this cut indicate the course of the gases. In each of these chambers some of the arsenious acid is deposited, and the permanent gases, such as are not condensed by passing through the chambers, are conducted out of the building by the chimney D. The covers E E, are removed when the arsenic is to be gathered in the chamber F.

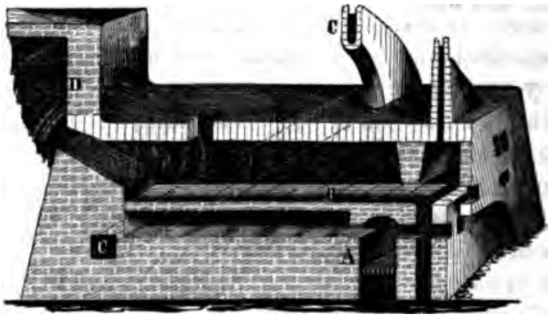
The operation in these furnaces is carried on chiefly in winter, in order that the cold air may favor the condensation of the poison. About a quarter of a ton of ore is charged at once, which forms a stratum of about five inches high over the hearth of the furnace. A heat of a couple of hours, with occasional stirring, is sufficient for impure ore, or that which contains nickel—which metal ought not to be oxidized. Pure ore is exposed for five or six hours to heat, and stirred every half hour. When no arsenic is exhaled from the pure ore, it is raked out and a fresh charge introduced into the furnace. Impure ore is not suffered to evaporate much arsenic. The roasted pure ore has a brownish-gray color, is about 33 per cent. lighter than the crude ore, and is now ready for being converted into smalt. The impure ore is generally exposed during a summer to the atmosphere.

In cases where the chief object of the roasting process is to obtain pure arsenious acid for commercial purposes, the furnace is provided with a large clay muffle, in which the pulverized ore is roasted. The gases from the fuel are thus prevented from coming in contact with the arsenic, which in consequence arrives in the condensing chambers more pure and white. No arsenic which is obtained by either of these processes is sufficiently pure for commerce; it is therefore re-distilled in cast-iron vertical retorts, and condensed in a wooden chamber. Or, if the arsenic is considerably pure, it is distilled in cast-iron pots and condensed in cast-iron cylinders, in which it appears in the form of a milky-colored glass. A roasting furnace, which is suitable to produce pure arsenic-meal is represented in fig. 318. A represents the fire-place; B the hearth, formed of fire-tiles; C the flues which conduct off the smoke from the fire; and D the flue which leads to the poison chamber. These furnaces work slow, but furnish a pure article.

The oxidized pure cobalt ore is ground with pure white sand,

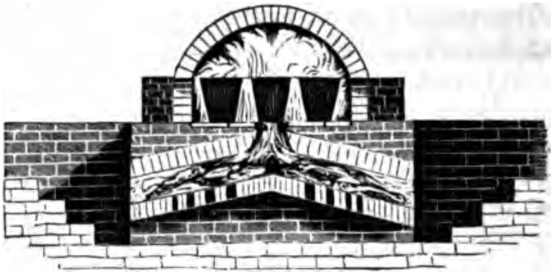
and smelted in crucibles to a slag, which is more or less of a dark blue color according to the quantity of oxide of cobalt present.

FIG. 318.



Six or eight pots are inserted in one furnace, which produce from ¾ to 1 ton of smalt in 24 hours. In fig. 319, a vertical section of a Norwegian smalt-oven is shown, the operation of which is easily understood. As wood is burned in this furnace, there are no grate-bars—a few holes in the floor of fire-brick and the doors of the fire-chamber supply the fresh air necessary for combustion. The pots are withdrawn through openings in the circular inclosure, which are shut by means of fire-tiles. The furnace is not provided with a chimney; the smoke escapes from small apertures in the roof, above the pots. Any glass-oven, or English zinc-distilling oven, may serve the purpose of melting smalt. The beauty of the color of smalt depends chiefly on the purity of the materials. Pure sand, of which about two or three parts are used, is necessary. Of course impure ore will not produce a fine color. The best color is obtained by mixing the finely-powdered zaffre-oxide and sand with two or three times its own weight of calcined

FIG. 319.



potash, and melting them at a low heat. The melted glass, while hot, is thrown into cold water, so as to break it into minute fragments. It is afterwards ground in a mill, such as is represented in figs. 320 and 321.

Fig. 320.

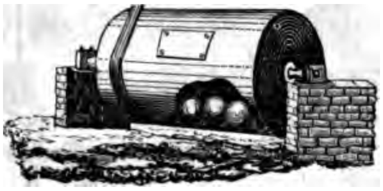
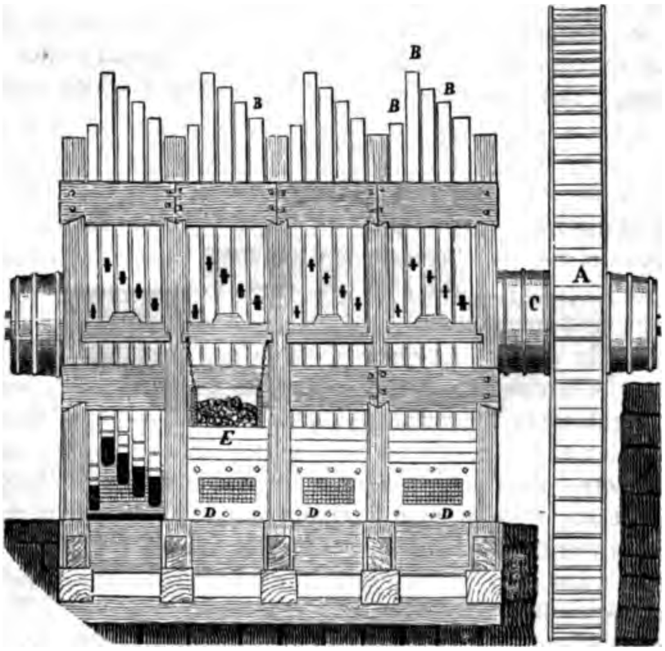


Fig. 321.



At the bottom of the earthen pots in which smalt has been melted, there remains a lump of a metallic mass, which is called cobalt speise, or nickel speise; it forms the bulk of ore from which nickel is obtained. We have alluded to this before.

CHAPTER VI.

Tin.—This is a beautiful metal; it is white and of a high lustre, similar to silver. It is softer than gold; but harder than lead, and very malleable. When in the form of a rod it is very flexible, and emits a peculiar crackling sound—tin-cry. . This peculiar sound is best perceived by bending a piece of it between the teeth; or biting one end of the ingot with the teeth and bending it by hand. When the metal contains only a few per cent. of lead the creaking does not occur. Tin melts at 442°, and resists a red heat very well; but at a white heat it evaporates, and burns with a blue flame. When heated to redness in free air it oxidizes rapidly, and forms a heavy coating of oxide of tin on its surface. This oxide contains 100 metal, and 27·2 oxygen. The specific gravity of tin is 7·29. In the United States, tin is not at present manufactured. The market is supplied chiefly by Europe. Some tin of inferior quality is derived from South America. English grain-tin is considered the best kind of this metal; next to that ranks the tin from Banca.

Most of the tin of commerce is impure. It is either accidentally or purposely adulterated with other metals. Iron and lead are the most common and most injurious admixtures. Pure tin is perfectly white; any shade of another color indicates the presence of other metals. Iron, copper, lead, and antimony impair the brightness of the metal, and cause it to become of a bluish or gray color and harder than pure metal. Arsenic causes tin, as well as other metals, to be more white and more brittle than the pure metal. Pure tin may be recognized, after some experience, by its tin-cry. This sound is short, or rather a succession of sounds, when the metal is impure. Pure metal emits a connected creaking, similar to sole-leather. It shows a white, dull, fibrous fracture when broken after repeated bending, similar to pure fibrous iron. The fracture of impure metal is crystalline, and more or less tinged with a strange color. The best test of tin is, to melt the metal and pour it into a clean iron mould; when its surface remains bright and polished in cooling, we may consider that it is pure; if spots are visible, or if the surface is dull, white, or gray, the tin is adulterated.

Ores.—There is but one tin ore which is of practical use, and that is the oxide of tin. The sulphuret of tin is another species, but so scarce as not to be available for smelting. Oxide of tin occurs in small veins traversing granite, gneiss, mica or clay-slate, or porphyry; it also occurs in the alluviums of the primitive formations—as the stream-tin of Cornwall. This ore is always crystallized, frequently in twin crystals; it is of a high adamantine lustre, a dark-brown or black color, and forms on being crushed a grayish brown powder; it is brittle, opaque, also nearly transparent when of a light color, and very heavy; its specific gravity is 6·7 to 6·9. The crystalline ores generally contain from 90 to 95 parts of oxide of tin, in 100 parts of crystals; the remainder is iron, manganese, titanium, and other substances. Pure oxide of tin consists of 79 metal and 21 oxygen.

The chief deposits of tin ore are in Cornwall (England), the East Indies, Germany, Russia, and South America. The United States have not as yet afforded sufficient tin ore for smelting. The New England States furnish specimens, and also the Southern States; but no vein of practical value has been discovered. It is reported that a vein of tin ore of considerable strength has been discovered in Missouri. This requires confirmation.

Alloys.—Tin imparts to most metals whiteness, hardness, and fusibility. It is in these respects similar to arsenic, but does not cause quite as much brittleness.

Pewter.—All the varieties of this alloy consist chiefly of tin and lead, with the addition of copper, antimony, zinc, and other metals. The best pewter always contains $\frac{1}{6}$ or $\frac{1}{5}$ of lead, and if little or no other metal, the alloy is hard, white, and without much lustre. A good composition for kitchen utensils is formed of 18 per cent. of lead and pure tin. Fine pewter is pure tin and a little copper, which causes the tin to be hard and sonorous, but impairs its bright color. The alloy becomes brown, particularly when too much copper is used; one per cent. of it may be considered too much, not often more than $\frac{1}{24}$ to $\frac{1}{2}$ per cent. is used. Zinc impairs the quality of pewter very much, but as it burns rapidly when melted little remains in the compound; when the quantity has been small, its presence adds to the purification of tin, and prevents, to a certain degree, its oxidation.

Britannia Metal.—This is also a kind of pewter. It consists of tin, antimony, copper, and zinc—88 tin, 7 antimony, 3 copper, and 1 zinc, is a common alloy for Britannia metal; which admits of being rolled into thin sheets.

One part of tin and 3 of lead form coarse, black, plumbers' solder, which melts at about 500°; 2 tin and 1 lead is a fine solder, which melts at 360°.

Tin combines readily with the precious metals—particularly with gold; 8 per cent. of tin in gold does not much impair its malleability—more than that causes gold to be hard. Tin and mercury combine very readily, and form amalgam. One tin, one lead, 2 bismuth, and 10 mercury, form a fluid alloy at common temperatures. It is used for coating the interior of glass globes, to which the solid metals adhere; the superfluous mercury is poured off. With iridium, and the platinum metals generally, tin forms hard compounds. The alloys of antimony, or arsenic and tin, are very hard and brittle. It alloys very readily with potassium, sodium, tellurium, and selenium. One part antimony and 3 parts of tin, form a ductile alloy which will bear much hammering without breaking.

Tin and bismuth form very interesting compounds which are little used; 45·3 tin and 54·6 bismuth, melt at 325°. These alloys are generally hard and brittle. A little bismuth improves the lustre, hardness, and sound of tin.

Speculum Metal.—An important application of tin is found in speculum metal. Equal parts of tin and copper form a white metal as hard as steel. Less tin, and a little arsenic added to the alloy, forms a very white, hard metal, of high lustre. Two copper, 1 tin, $\frac{1}{16}$ arsenic, form a fine speculum metal. A composition of 32 copper, 16·5 tin, 4 brass, 1·25 arsenic, is hard, white, and of a brilliant lustre.

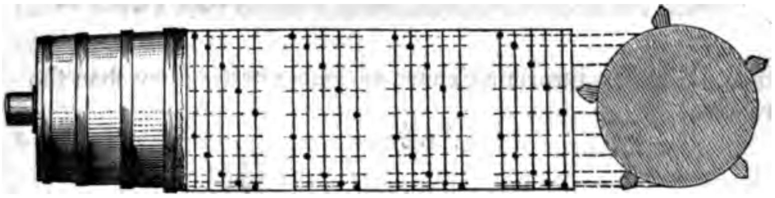
Tin and sulphur form a bright yellow metal, bronze powder, Mosaic gold. This has been the cause of much deception; it is obtained by heating equal parts of pure tin-filings, sulphur, and sal-ammoniac together; or various compounds of tin, mercury, sulphur, and sal-ammoniac. A variety of colors is produced by employing alloys instead of pure tin.

Tin-Plate.—The most interesting alloys of tin are those of copper and iron—of the first we shall speak hereafter. Sheet-iron, coated with tin, forms tin-plate; this alloy unites the qualities of both metals in a high degree. When the thin sheets of iron are coated with tin, the core or interior of the plate is almost pure iron, while the exterior is chiefly tin; the alloy is between both. In order to cover sheet-iron with tin, it is freed from oxide and dipped in melted tin; or the heated iron is rubbed over with tin. Not only iron, but also copper and other metals are coated with tin in a similar manner.

Uses of Tin.—This metal is extensively used as an alloy for kitchen utensils, and as a part of bronze metal in manufactures. The dyer's kettles which are used for boiling delicate colored goods are formed of it in its pure state. Tin and lead is rolled or cast in the form of tin-foil, and extensively used. It may be drawn into fine wires, which are moderately tenacious, and not elastic. Tin tube is used for gas pipes, and a variety of other purposes.

Manufacture of Tin.—The smelting of this metal is extremely simple, if a small loss in metal is disregarded. The raw ore is generally a mixture of veinstone, and crystals of ore; this is assorted by hand into rich tin ores, tin mixed with copper, and other ore, and poor ore. The rock is separated from the ore by hand as much as possible and thrown away. The various qualities of ore form various qualities of metal, and are separately smelted. The ore, each class by itself, is brought to a stamping mill, such as is shown in fig. 322; and converted into a sand of more or less fineness, according to the form or size of the crystals of ore, or the nature of the rocky matter. By washing the ore in the stamping mill and without crushing it finer than is absolutely necessary, the ore sand is so far freed from impurities, and concentrated as to contain from 60 to 70 per cent. of metal. The meshes of the wash sieves in the stamping mill should be 160 to the square inch.

FIG. 322.



Tin ore is heavy, and is easily washed and freed from most of the impurities when the crushed sand is not too fine. The coarse parts, which, in flowing from the stamps, are first deposited in the labyrinth, are washed in the tossing tub, fig. 323. The slimes, or slicks, which contain less metal, are washed on the rack-table, fig. 324.

Crushing rollers are employed instead of stampers, in England. They require less attention, but are as expensive in their operation. Stampers furnish a cleaner, and more uniform ore than the rollers.

FIG. 323.

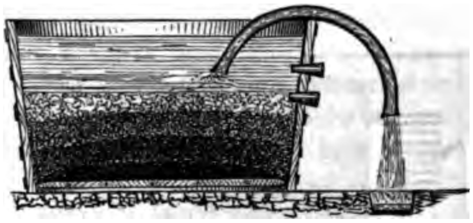


FIG. 324.

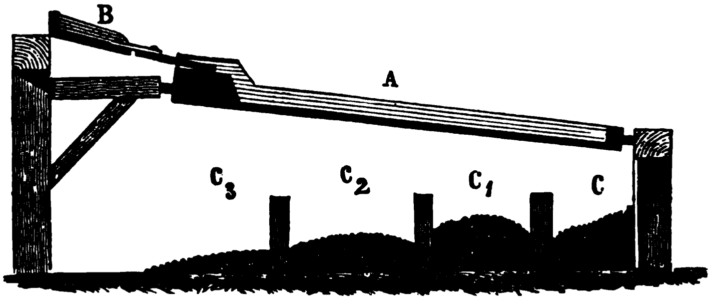
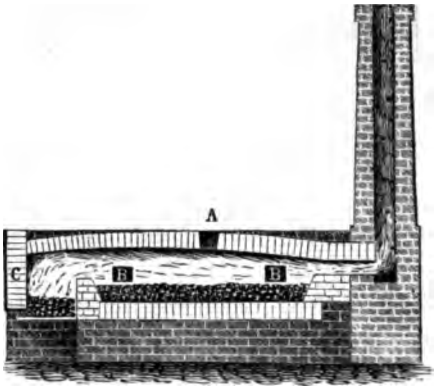


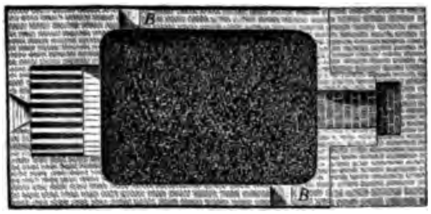
FIG. 325.



The ore thus concentrated and purified is roasted in order to remove volatile substances, such as sulphur, arsenic, and others. This operation is invariably performed in a reverberatory furnace.

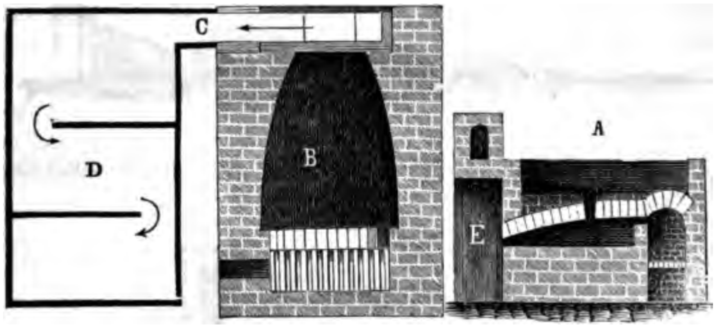
The English furnaces of this kind, are of the form shown in figs. 325 and 326; the hearth is from 6 to 8 feet long, and equally as wide. The roof is 28 inches high at the fire-bridge, and slopes gradually towards the flue. The furnace is also provided with a condensing chamber for arsenical fumes.

FIG. 326.



In fig. 327 A is the vertical section, and B a plane section of a German roast oven for tin ores. The poisonous fumes are conducted from the hearth by the channel C, to the poison chamber D. The stirring, or turning of the ore is performed from E, where a large door of sheet-iron is inserted for the purpose.

FIG. 327.

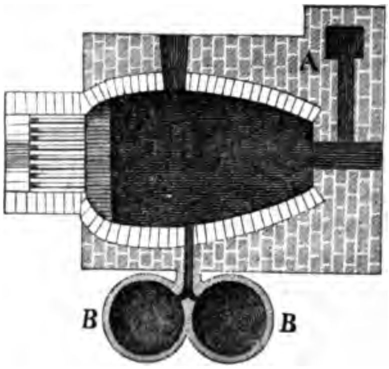


Six hundred weight of ore, which is thinly spread over the hearth, forms one charge; the calcination of which takes from 12 to 18 hours, according to the amount of impurities. Sulphur adheres most tenaciously to the ore, and as the sulphuret of tin is very fusible, only a red heat can be imparted to the ore to prevent its melting. Diligent stirring by means of an iron bar, flattened at one end, will prevent kerning, or agglutination of the sulphurets, which, when it happens, makes it necessary to grind the ore. Most of the metals are by these means oxidized; and as the oxide of tin is heavier than almost all others, they may be removed by subsequent washings. When the ore is sufficiently calcined, which is shown by its no longer emitting sulphurous vapors, it is removed from the furnace, and exposed in small heaps to the action of the atmosphere for a few days.

The influence of the air on the roasted ore decomposes the remaining sulphurets and forms sulphates. When the ore thus oxidized is thrown into water, the sulphates are dissolved and carried away in a fluid condition. Copper, which may happen to be in the solution, is recovered by running the fluid into preserving tanks, and precipitating the metal by means of metallic iron. The ore thus roasted, oxidized, and lixiviated, is washed once more on the rack-table, and the light parts removed. The heaviest parts form the best ore; and that portion remaining on the middle of the table is sent once more to the stamps to be crushed and washed, after which it also forms ore for the smelting furnace. The value of these various kinds of ore is ascertained by an assay, as it is described in the second part of this book.

The smelting of tin ores is effected in reverberatory furnaces when only an impure metal is expected; but in the blast furnace when the ore is pure. The reduction of the ore is performed in Cornwall, in reverberatory furnaces, one of which fig. 328 shows in plane. The form of the furnace is not essentially different from any other, except in the addition of the two round basins B B, into which the melted tin is drawn off, and ladled out into moulds.

Fig. 328.

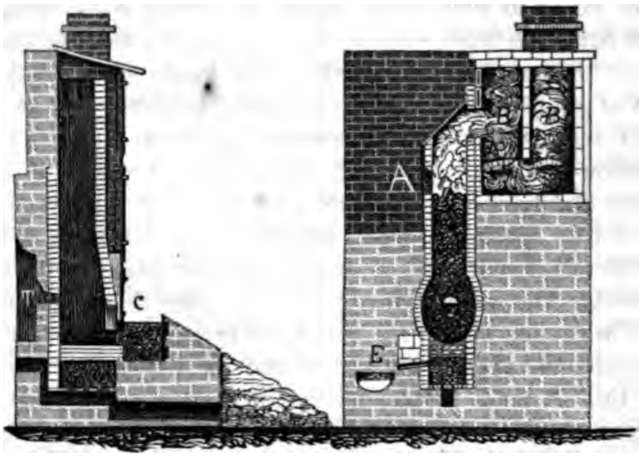


The chimney A is put on one side of the furnace to afford access to the hearth from behind; it must afford a strong draught, and should be at least 50 feet high.

When the furnace is properly heated the ore is charged, and an aperture over the firebridge in the roof is opened, which admits of the escape of obnoxious fumes. Previously to charging, the fine ore is intimately mixed with fine mineral, or fine charcoal, the former of which is preferable, to the amount of about $\frac{1}{8}$ in weight, also with a little slacked lime, and fluor-spar, as flux. About a ton of ore forms one charge. The heat on the ore is at first gentle, so as to prevent a union of the oxide of tin with quartz, which cannot easily be separated when once formed. From 6 to 8 hours' heat are imparted to the ore without stirring the mass; after that time the door is opened and it is thoroughly worked to effect a separation of the metal and the slag. When the metal has descended into the basin of the hearth, the scoria which flows on its top is drawn off and preserved, of which the first or upper portions are poor in metal, but the lower are rich, as well in grains as in combination with the gangue of the ore. These slags are saved and re-smelted. When the metal is thus skimmed, it is drawn into the circular basins by opening the tap-hole in the side of the furnace. The fluid metal is then suffered to separate from the slags more perfectly than could be accomplished in the furnace. It is ladled out, however, before it is too cold. The tap-hole at the furnace is stopped up with a plug of dry wood, while the operation of smelting is going on.

The annexed engraving, fig. 329, shows two vertical sections of a blast furnace for smelting tin. At A is the mouth for charging the furnace; B B are two chambers for the condensation of volatile metals. The in-wall of the furnace is formed of firebrick, and the bottom of firm fireclay. In the vertical section in an opposite direction we see the position of the tuyere T more distinctly. At the breast C, is a basin communicating with the interior of the furnace; the metal gathers there, and the slag on the top of it flows off over the dam D. At the side of the dam is a round basin indicated at E, into which the metal is occasionally tapped and ladled out into iron moulds. The in-walls of the furnace may be formed of granite, or feldspathic rock, equally as successfully as of firebrick. The height of the furnace is not often more than 6 feet; where much ore is smelted, it is found to be as high as 9 feet. The area at the tuyere is not less than 144 square inches, nor more than 230. The tuyere is about 4·5 inches above the back part of the bottom. The latter slopes 25° from the tuyere to the tymp, so that the hot metal may not be exposed to the action of the blast.

Fig. 329.



When this furnace is thoroughly heated, the ore is charged regularly with charcoal. The ore meal is generally mixed with fine charcoal, and damped to cause it to adhere together. The lump charcoal for smelting is also used in a damp state; dry coal works too hot at the top. When a certain quantity of ore has been smelted and the metal removed from the furnace, the scoria and refuse ore, and also the rubbish which may contain tin, are smelted. The scoria from the reverberatory furnaces, from which the grains of metal have been removed by stamping and washing, are also smelted in the blast-furnace. The metal resulting from the poor refuse ore and slags is very impure, and adulterated with many other metals.

Refining of the tin is a necessary operation in all cases; it is effected by liquation, lixiviation or oxidation. Liquation is performed in a reverberatory furnace, similar to that in which the smelting is done, but it is provided with a more sloping hearth. The pigs of tin are placed near the firebridge of the furnace-hearth, and on being moderately heated, the tin melts first and flows into the refining basin formed in the hearth. When the blocks are exhausted of pure tin, skeletons of the pigs remain as a refractory residuum, consisting chiefly of ferruginous alloys. This re-melting may be also performed in a blast-furnace, but the metal does not then arrive as pure in the basin as when purified by liquation in the reverberatory. In either instance the metal is run from the furnace into a large iron pan or kettle, which holds from 3 to 5 tons at once. The kettle is placed over a fire-grate, and heated so as to continue the metal in a fluid state. Into this metal bath, billets of green wood are plunged, and set in a rotary motion by a machine placed above the kettle. The disengagement of gas from the wood sets the metal to boiling, and the oxygen of the gases oxidizes those metals which are more subject to oxidation than tin. The froth which is thus formed, and which consists chiefly of foreign metals, is skimmed off the surface, and reserved for re-smelting along with the slags. From 3 to 4 hours are generally required for refining, or thus working the hot metal by wood. The wood is then removed and the tin allowed to settle. On cooling slowly the metal separates into different strata, of which the upper is the purest, and the lowest the most impure tin. After a couple of hours, it is gently ladled out into cast-iron moulds, and is ready for market. The quality of the tin depends on the order in which it has been dipped; the first blocks contain, of course, the purest metal, and the last the impure alloy. The latter are generally once more subjected to liquation and refining.

The moulds are, in some instances, made of granite, and are of a size sufficient to contain three hundred weight of metal. The Germans cast much of their tin in the form of sheets; these are formed by casting the metal over a polished copper plate, four feet long by two feet wide.

The finest metal is formed in the blast-furnace; that from the reverberatory is always more impure, although smelted from similar ores. And, as the poor ores, slags, froth, and the residue of liquation must be smelted in the blast-furnace, in all instances the use of that kind of furnace must be considered the most judicious for smelting tin. The operation in the reverberatory, consumes about two tons of mineral coal to one ton of metal; the blast-furnace consumes nearly 1·5 ton of charcoal for the same purpose. Where the difference in the price of these kinds of fuel is sufficient to pay for the loss in the quality of the metal, there may be a reasonable cause for the use of reverberatory furnaces. The expenses of smelting a ton of tin may amount to about $20 in either the blast-furnace or the reverberatory. The latter yields more metal from the same kind of ore; for the blast loses 15 per cent. of metal, while the reverberatory loses only 5 per cent. The superiority of the metal from the first generally repays this loss, which, in case the price of impure tin is only one cent less per pound than pure tin, is nearly sufficient. Grain-tin is formed of the finest blocks; these are heated nearly to melting, and then dropped from a considerable height; the metal is thus broken, and forms elongated grains. This may be considered a second refining operation on fine metal.

For thin sheet tin, such as tin-foil, the purest kind of metal is required, which is cast in sheets and then rolled or hammered into the desired form. It is asserted that impure tin forms better foil for glass mirrors; this can apply only to a peculiar kind of impurity. The sheets do not assume so high a polish when laminated cold as if done at a moderate heat; those manufactured in winter are therefore not so bright as those made during summer, but are more suitable for covering glasses.

The production of tin in the world may amount to about 10,000 tons, of which one-half is manufactured in England, nine-tenths of the other in the East Indies and South America, and the remainder in Germany. The price of tin fluctuates from 16 to 20 cents per pound.

Antimony.—The properties of antimony are in many respects distinguished from those of other metals, particularly in its tendency to crystallize. When the metal is melted in a pot and suffered to cool on its surface, and the fluid part then cast off, a mass of beautiful crystals remains in the pot. Antimony is very brittle. It may be pulverized in a mortar. It is silver white and with a brilliant lustre. It fuses at about 800°, or at a dull red heat, and is volatile at a white heat. Its specific gravity is 6·7. The metal in its pure condition is not in use, but alloyed with other metals it is much employed. No antimony is smelted in the United States.

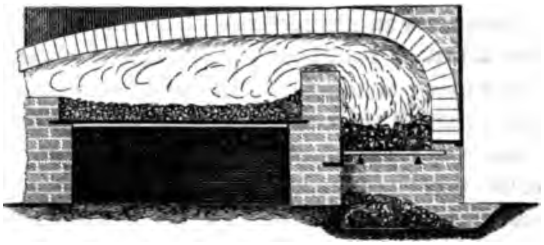
Ores.—The only useful ore of antimony is its sulphuret; no other kind is obtained in sufficient quantity to be smelted. The sulphuret of antimony occurs in masses, consisting of crystalline needles which are closely united. It is of a metallic lustre, of a gray color, and forms a gray powder. When gently heated, it turns black, or is iridescent. It is extremely fusible, and melts in the flame of a candle with the exhalation of a sulphureous smell. After being heated the powder is very black. This ore consists of 72·86 metal and 27·14 sulphur. Its specific gravity is 4·1 to 4·6. Sulphuret of antimony occurs in and near the veins of sparry iron ore, with heavy spar, blende, galena, quartz, and other minerals. It occurs at Carmel, Penobscot county, Maine; at Cornish, New Hampshire; in Maryland; in Washington county, Missouri; and it is said to be in large quantities in Illinois, about 30 miles north of Edwardsville. Veins of this ore occur in Mexico. Most of the metal in market is obtained from Germany.

Alloys.—All the antimony metal of commerce may be considered an alloy. It is never pure, but contains iron in all instances. Antimony and tin, melted together in equal parts, form a moderately hard, brittle, but very brilliant alloy, which is not soon tarnished, and is frequently employed for small speculums in telescopes. Of all the metals, antimony combines most readily with potassium or sodium. These alloys are obtained by smelting the carbonaceous compounds of these metals, or their oxides mixed with carbon. The presence of other metals, such as copper or silver, does not diminish the affinity of these metals for antimony. The alloy thus formed of the alkaline metals and antimony is not easily evaporated by a strong heat. Arsenic and antimony combine in all proportions, and form, unexpectedly, a tenacious alloy, which is very fusible, compact, and often of a granular texture. It has been remarked, in speaking of the alloys of iron, that this metal alloyed with iron causes the compound to be extremely hard. Eighty parts of lead and twenty of antimony form type metal; to this commonly five or six parts of bismuth are added. Tin, 80 parts, antimony 20, is music metal; it is also composed of 62·8 tin, 8 antimony, 26 copper, and 3·2 iron. Plate pewter also contains from 5 to 7 per cent. of antimony; 89 tin, 7 antimony, 2 copper, 2 iron, is one of these compositions. Britannia metal contains frequently an equal amount of antimony. Queen's metal is 75 tin, 8 antimony, 8 bismuth, and 9 lead.

Uses of Antimony.—Besides its employment in medicine, it is much used for forming alloys; of these type-metal, and antifriction-metal—which is type-metal with the addition of copper—are those most used. Crude antimony is employed for purifying gold.

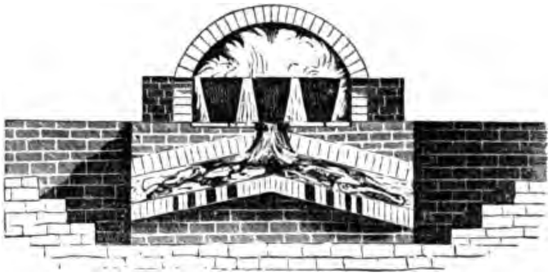
Manufacture.—The smelting of this metal is very simple. It is easily revived from its ore, which, however, is attended with a heavy loss of metal. The crude ore is picked by hand; the pieces are broken to the size of an egg; and, by means of a hand-hammer, the gangue, such as quartz, barytas, or carbonate of lime, is removed. These pieces may be heated in an earthenware pot, in the bottom of which there is a small aperture. The sulphuret of this metal, melting at a very low heat, will flow out from the gangue, and may be gathered in another pot set below. The operation used to be performed in this manner; but, as it is expensive, the ore is at present melted in a reverberatory furnace, similar to that shown in fig. 330, the hearth of which is very concave, and formed of sand. In the centre of the hearth, at its deepest part, there is a tap-hole which communicates with one of the long sides of the furnace. The ore, on being sorted, is spread over the hearth of the furnace, and is there melted. The tap-hole is stopped by dense coal-dust while the reduction is going on. About three hundredweight of ore is charged at once, mixed with iron ore or hammer slag, and heated, with an occasional stirring. Eight or ten hours are sufficient to finish one heat, after which the metal is tapped, the scoria removed, and the furnace charged anew.

Fig. 330.



The metal thus obtained is not pure. It contains iron, sulphur, arsenic, lead, and copper; from most of these admixtures it may be freed to a certain extent, but not entirely. This metal

Fig. 331.



is refined by re-melting it in crucibles, arranged on the hearth of a reverberatory furnace, or a furnace similar to the one shown in fig. 331. The pots contain about 30 pounds of metal, which is covered with coal-dust. These are exposed to a low, uniform heat for some hours. Most of the foreign metals are thus oxidized, and may be removed after emptying the crucibles.

The smelting operation is in some instances divided into two manipulations; the one, or first, is a process of liquefaction, in which the crude antimony is melted in vertical pipes and thus separated from the gangue, which remains in the retort while the former filtrates through the perforated bottom. In this operation much of the antimony is lost. A part of it adheres to the gangue, which in poor ores amounts to 25 per cent., and is never less than 10 per cent. Part of the crude antimony also volatilizes, which increases the loss. This loss is, therefore, an important object where the ore is expensive; and it may be in most cases the best plan to stamp and wash it while crude, free it from rocky matter, and then subject it to reduction by direct smelting. The specific gravity of the ore is sufficiently great to remove most of the gangue. Metallic sulphurets of other metals than antimony, of course, remain with it.

The crude antimony, or the concentrated ore sand, is smelted with metallic iron, or iron ore; and since it is difficult to add just as much iron as is required to absorb all the sulphur, and as too much imparts iron to the metal, the practice is to add either carbonate or sulphate of potash or soda, and also fine charcoal-powder to the ore. One part of metallic iron to 2 or 2·5 parts of crude antimony, ought to absorb all the sulphur; but when no other flux is present, about 20 per cent. of antimony remains in the slags. By using 42 iron to 100 of crude antimony, with 50 carbonate of soda and 5 charcoal, nearly the whole of the antimony is revived. Instead of metallic iron, any kind of pure iron ore may be employed with more charcoal, but its metallic contents should come near the above quantity.

In refining the crude metal of antimony in crucibles, it is advantageous to soak the charcoal powder with which the metal is covered, in a strong solution of carbonate of soda. When the metal is not sufficiently pure after the first refining, the operation is repeated. In all the operations with antimony, a high heat must be avoided, for the metal as well as the sulphuret is very volatile. A fusible slag increases the yield of the ore.

Bismuth.—This is a rare metal, but its distinguished qualities are that it is very fusible, and causes other metals to become so. It melts when pure at 480°; it may be distilled in a close vessel, and then crystallizes in lamina. It is very brittle, like antimony, and of a brilliant lustre; its color is white, tending to flesh-color. Its specific gravity is 9·83, which may be increased to 9·88 by hammering. It expands in the act of cooling, which renders it peculiarly suitable for castings.

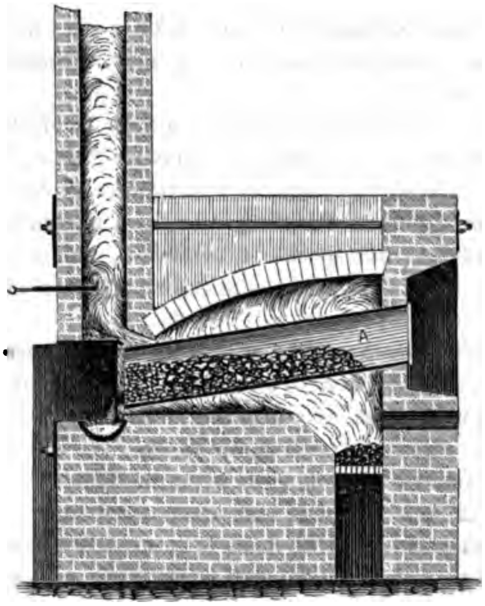
Ores.—There are many minerals which contain bismuth, but they do not often occur in such quantities as to make the extraction of the metal profitable. The metal is not very valuable, and notwithstanding its scarcity it is sold at a low price. It occurs native, and is then easily obtained. Native bismuth is found in Monroe, Ct., where it is associated with wolfram, galena, blende, and quartz; also in Chesterfield, South Carolina; and, of course, in many localities of other parts of the world. Sulphuret of bismuth occurs at Haddam, Conn. The carbonate is found in the gold district of Chesterfield, South Carolina; and the sulphuret and lead and copper, at Lubec lead mines, in Maine. Telluric bismuth exists in the gold regions of Virginia and North Carolina. All the metal in market is obtained almost exclusively from cobalt-speise, at the smalt works of Germany. This residuum, from which also nickel is extracted, contains on the average 7 per cent. of bismuth.

Alloys.—The compounds of bismuth are distinguished by fusibility, at a lower degree of heat, than those of most other metals. Eight parts of bismuth, 5 of lead, and 3 of tin melt at 202°. Two bismuth, 1 lead, 1 tin, melts at a little lower heat. The addition of mercury increases the fusibility of these alloys. One bismuth, 2 tin, 1 lead is soft solder for pewter. Clichés for stereotypes are composed of 3 lead, 2 tin, 5 bismuth; this alloy melts at 199°; 45·5 bismuth, 28·5 lead, 17 tin, and 9 mercury, is an alloy for plugging teeth; it fuses at 149°. An amalgam of 20 bismuth and 80 mercury is used for silvering the interior of glass globes. Like antimony, bismuth forms an alloy readily with the alkaline metals. Its affinity for arsenic is very weak, like that of phosphorus; both of these substances may be evaporated from the hot metal almost entirely. All its compounds with precious metals are very brittle. Bismuth has been proposed instead of lead for refining silver; but the experiments performed with it were not satisfactory. A compound of tin and bismuth is stronger, harder, and more sonorous than pure tin; and for these reasons it is added to pewter. An alloy of equal parts of lead and bismuth is heavier than the mean density of the two metals, it being 10·709.

Uses.—Bismuth is scarcely used alone; it is chiefly employed for imparting fusibility to alloys. Besides the above-mentioned applications, it is used in the alloys of which safety-plates and plugs in steam-boilers are made. Its oxides are used as cosmetics; also as paints, and printing colors.

Manufacture.—The operation of smelting bismuth is extremely simple; the metal having but a weak affinity for other substances is obtained by simply heating its ore. The cut, fig. 332, shows a modern liquation furnace, by which the metal is obtained. A, is a cast-iron retort, at the highest part of which the crude ore is charged. B, shows a cast-iron bowl into which the metal flows. About half a cwt. of broken ore is charged in each retort, of which there are four in a furnace side by side. This quantity nearly half fills a retort, so that the upper part of it is empty. The lower end of it is closed with a clay plate, or slab, provided with an aperture for the discharge of the melted metal.

FIG. 332.



The pipes, when properly ignited, soon cause the metal to flow into the dish B, which contains some charcoal-dust. By applying a brisk fire and some stirring to the ore, all the metal contained in it is obtained within half an hour. The residuum of the ore is now scraped out of the retort into a trough with water, and the pipes are filled afresh. About a ton of ore is smelted in a day of eight hours. The metal is remelted, cast into iron moulds in the form of ingots, and is now ready for the market.

The metal thus obtained is not pure; but it may be purified by remelting in a flat earthen, or rather a bone ash-dish, at a low heat, removing the dross as it appears on the surface of the metal. It is advisable to melt the metal thus obtained in a purer form in a blacklead pot, and then cast it into the mould for ingots. Bismuth cannot be freed from silver by these means, in consequence of which the article of commerce always contains some of that metal. The production of this metal amounts to nearly 10,000 pounds.

Lead.—This is a metal generally known. When pure, it is blue-white, of high lustre, and extremely soft. It is almost inelastic, and may be bent, when in sheets, like moist sole-leather. This softness admits of its being used, like graphite pencils, for writing on paper. Its specific gravity is 11·44; or, when pure, only 11·35. Lead admits of being rolled into thin sheets, and is easily drawn into pipes; it has little strength. It melts, or crystallizes at 600°; some assert that it does not melt at that degree of heat, but at 20° higher. A variation in the melting heat may be observed with most other metals: impure is always more fusible than pure metal. When common lead is exposed to a melting heat, its point of fusion rises with the time it is exposed to that heat. At a white heat lead evaporates, and it may be obtained crystallized when the heat is gradually diminished; sudden cooling prevents the formation of large crystals. All the lead of commerce contains iron, copper, and more or less silver.

Ores.—A large number of minerals contain lead; but the chief source of this metal is galena, and we may assert that lead is exclusively obtained from that ore in this country. Lead occurs native, but it is of no practical use. It occurs in combination with sulphur, selenium, tellurium, antimony, oxygen, and other substances. Most of the innumerable varieties of lead ore enumerated in mineralogical works occur in this country; few of them, however, are used for the manufacture of metal, except galena. Carbonate of lead has been obtained at Phenixville, Pa.; in Washington and Jefferson counties, Mo.; at a cave, in Rock county, Ill.; Wythe county, Virginia; and in particularly beautiful crystals at the Washington mine, N. C. All of these ores form mere cabinet specimens. Phosphate of lead occurs at almost every lead mine, as a faint green or gray substance, either crystallized or without definite form; chlorides, sulphates, and other salts of lead are also found; but they are of little interest to the metallurgist.

Galena.—Sulphuret of lead. This may be considered the matrix of all other lead ores; where they exist, we are sure to find galena. It is always crystallized, however minute the crystals may be. The form of the crystals is a cube composed of rectangular plates. The color of the ore is gray, similar to that of the polished metal, which it also resembles in lustre. It forms a gray metallic powder when rubbed. Its specific gravity is 7·3 to 7·7. Galena consists of 86·66 lead, and 13·34 sulphur. The ore contains also, at times, selenium, zinc, silver, copper, antimony, and other metals. Silver is the most valuable of these admixtures, and frequently is extracted from the metal. German galena contains from ·03 to ·05 per cent. of silver; the English, ·02 to ·03; the ore at Monroe, Ct., 3 per cent.; Eaton, N. H., ·1 per cent.; and that from the State of Arkansas may contain from ·003 to ·05 per cent. Galena occurs in beds and veins, both in crystalline and stratified rock. It is often associated with blende, iron ore, copper pyrites, and a variety of other lead ores. It occurs in gangue of heavy spar, calc spar, quartz, and other substances. The most extensive deposits of it in the United States are in Missouri, Illinois, Iowa, Wisconsin, Arkansas, Virginia, N. Carolina, and California. The lead ores of Missouri extend over 3,000 square miles. From the Mississippi river, about 60 miles above St. Louis, they extend 70 miles in length and 45 miles in width, over a sterile, rolling country, a highland prairie. The soil is reddish, colored by iron, with clay, full of flint and quartz pebbles, to the depth of ten or twenty feet. The lead region of Wisconsin is equally extensive as that of Missouri, if not more so; it comprises about 5,000 square miles, extending into Iowa and Illinois. The diggings, or mines, in these regions, do not often exceed a depth of 25 or 30 feet. Immense masses of ore have been extracted from these ditches. These regions, and those of Missouri, furnish all the lead which is at present manufactured in the Union, with the exception of very little smelted on the eastern side of the Alleghanies. Considerable quantities of lead ore occur in the State of New-York; in St. Lawrence county, Sullivan county, Columbia county; in the States of Maine, New Hampshire, Massachusetts, Virginia, North Carolina, and Tennessee, there are workable mines. More than nine-tenths of the lead consumed in the United States is derived from the north-western lead mines, which produced, last year, in pounds, about 40 millions, and can furnish, without much exertion, twice as much. Galena is not free from foreign metals, of which silver is always present. This ore is, therefore, not only an accidental silver ore, but it may be considered argentiferous in all its varieties. The amount of silver in lead ore is easily ascertained by an assay, and ought to be thus determined when it is doubtful. As a a general rule we may state, that the purest kinds of galena contain the least silver. The ores of the secondary and younger formation, particularly the ore of the limestone of that period, is always poor in silver. All deposits of galena which occur in heavy masses are also poor in silver. Galena which in small veins ramifies a stratified rock is generally rich in silver, and the smallest branches and forks are richest. The heaviest deposits of galena occur in limestone rock. The dimensions of a vein diminish as it penetrates sandstone strata, and grow still smaller in traversing shale or slate. In these rocks the metal is frequently replaced by clay or fragments of rock, and the vein does not show any ore.

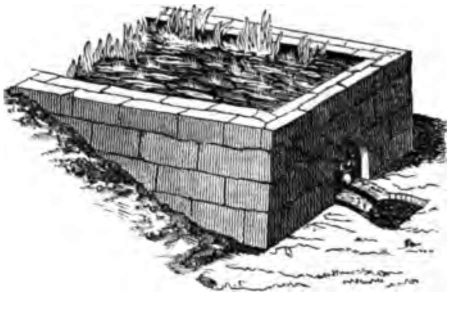
Alloys of Lead.—A very extensive use of the alloys of lead is made in type metal. Nine lead and one antimony forms common type metal; seven lead and one antimony is used for large and soft type; six lead and one antimony for large type; five lead and one antimony for middle type; four lead and one antimony for small type; and three lead and one antimony for the smallest kinds of type. Type metal frequently contains tin, copper, bismuth, and other metals. Stereotype metal is generally lead alloyed with antimony in the rates of 4 to 8 of the former to one of the latter; to this is always added some bismuth, tin, and frequently a little copper. Soft solder varies from 66 lead to 33 lead in 100 parts, the rest is tin. A small amount of bismuth renders lead tougher; equal parts of each and bismuth form a brittle alloy. Lead and tin melt together in all proportions, forming a harder and tougher metal than either alone. A small addition of lead to brass causes the latter to be tougher and more suitable for use in the machine shop. Lead has a strong affinity for carbon; oxide of lead mixed with fine carbon, and heated in a covered crucible, forms a black carburet of lead. Lead unites with potassium or sodium like antimony, but does not absorb so large quantities of the alkaline metals as the latter. Arsenic has a strong affinity for lead, and combines with it on covering melted lead with arsenious acid; arsenic-lead and oxide of lead is thus formed. This alloy, 98 lead and 2 arsenic, is used for making shot, by dropping the fused metal from a high elevation in a shot-tower into a basin of water; or throwing the fluid metal down a stack of limited height, in which a strong draught of air is produced by a blast-machine. Mercury amalgamates very readily with lead. A rod of lead, bent in the form of a syphon, will transfer mercury from one vessel to another in the same manner as lamp-wick conducts oil. An amalgam of lead crystallizes similar to that of gold, from which the superfluous mercury may be separated by pressing it through buckskin. Copper and lead do not combine very readily, they require a white heat for union. The alloy thus formed, under the influence of a high heat, must be suddenly cooled, or both metals will separate in cooling. Lead may be separated from copper by liquation, as practised in refining tin; but all the lead cannot be removed by these means; a small quantity always adheres tenaciously to copper. This alloy is brittle; a little lead is injurious to copper. Organ pipes consist of lead alloyed with tin, about half and half. This alloy is cast, instead of rolled, in the desired form of sheets, in order to obtain a crystallized metal which produces a finer tone. The sheets are formed in casting the metal on a horizontal table, the thickness is regulated by the height of a rib, or bridge, at one end, over which the superfluous metal flows off. The rough sheets thus obtained, are planed, by means of a carpenter's plane, bent up, and soldered. An alloy of 19 lead and 29 tin forms a metal of high lustre, which, when cast over a polished glass or metal plate, shows a most brilliant polish. When ends of glass rods, previously ground to the forms of cut precious stones, are dipped into this melted alloy, convex metal cups are formed which resemble the sparkling of diamonds. This alloy is soft, and cannot bear wiping with a cloth.

Uses of Lead.—The application of lead for pipes, cisterns, and domestic utensils is generally known. It is extensively used in manufacturing white paint, whitelead, and carbonate of lead. The rich colors of chromium are chiefly lead and that metal. The salts of lead are poisonous; and those who make use of this metal for conducting water or forming cooking utensils, ought to reflect before adopting it. Lead in sheets is inserted in foundation-walls for preventing dampness in dwellings. It is worthy of attention that iron bars, fastened by means of lead into stones, have been protected against corrosion by this metal; we find iron rods in old buildings, which have thus been preserved for centuries.

The total annual production of lead may be estimated at about 120,000 tons; of which the United States furnish about 20,000 tons; Spain 30,000 tons, and England 40,000 tons; the remainder is manufactured in other parts of the world.

Manufacture of Lead.—Although lead may readily be revived from its ores by applying a moderate heat and by simple means, yet, to obtain as much metal as possible at the least cost, has given rise to a variety of forms in furnaces and methods in the treatment of ores. Galena is reduced simply by melting it in a black pot. If a Western backwoodsman wants shot or bullets, he will kindle a fire in a hollow tree or an old stump of a tree, place some galena on the charred wood and melt it down. After cooling, he finds the metal at the bottom of the hollow. Formerly lead was smelted in log-furnaces, in Missouri—a rude kind of square furnace, constructed of logs or stones. Fig. 333, shows such a furnace. The front wall of such a furnace is about 8 feet wide, and 7 high. The hearth in the bottom of the interior is about 2 feet wide, 8 feet long, and 10 or 12 inches high, forming ledges or boshes with the side-walls 1 foot in width. The arch in front,

FIG. 333.



which admits air into the furnace, is about 2 feet high and wide, and is temporarily shut by stones, clay, or brick. A basin in front of the furnace receives the fused metal, from which it is ladled into the pig-moulds. The operation in this furnace was simple; a layer of heavy logs was placed horizontally in the bottom; then billets of split wood were set upright, and these covered with galena; the top of the ore was covered by small wood. A fire kindled in the front arch will char the lower parts of wood first; and by the time the heat is conveyed to the ore sufficient for melting, the hot charcoal below will expel sulphur and precipitate the metal, which flows out as it is formed. One heat requires 24 hours; after which the furnace is cooled and the ashes removed; then it is charged anew. About 50 per cent. of metal is thus obtained from the ore. The ashes which remain contain much metal, and are subjected to a second smelting in the ash-furnace. Both these kind of furnaces are now obsolete; they are replaced by more perfect ones.

In the system of smelting lead ores there is more variety than in any other class of smelting operations. The ore is not generally roasted in this country previous to smelting, although it is in others. A preparation of the ore—such as crushing and washing—is not practised here, however carefully done in other parts of the world. We shall describe the various methods, and allude to such apparatus and operations only as are approved of at the present time.

The method of smelting lead at the northwestern mines in Wisconsin, Missouri, and the adjoining States, is to pick the ore well by hand and remove gangue, which consists chiefly of heavy spar and quartz, and then smelt it in reverberatory or blast furnaces. The rich slags obtained by these processes are once more subjected to smelting in a slag-furnace. There is not much difference in the form of the reverberatory furnaces for smelting lead or other metals; that which is represented in figs. 334 and 335, will impart quite as correct an idea of such a furnace as any other form. The furnace hearth for smelting lead is about 8 feet long, and 6 feet wide; the arch is 24 or 26 inches above the bottom. There are 2 or 3 small work doors on each side of the furnace, beside the tap-hole for the metal, and one for the scoria. The hearth is formed of poor refractory slags, firmly rammed down to form a basin towards the tap-side. From this side the metal is run into an iron kettle, from which it is ladled into moulds.

In the middle of the roof there is an aperture for charging the ore into the furnace.

Fig. 334.

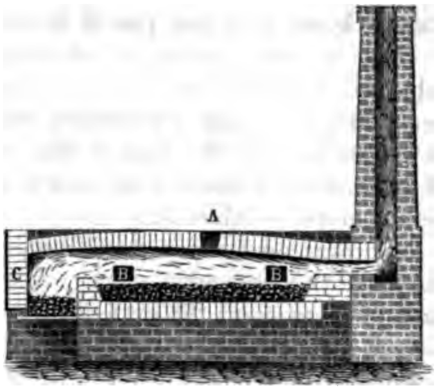
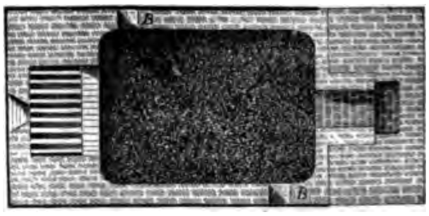


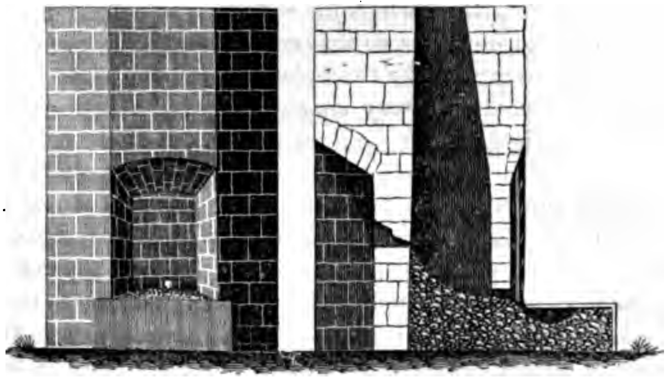
Fig. 335.



When the furnace is heated and charged with about a ton of ore, a gentle heat is applied for the first couple of hours. All the doors are closed during this interval, and the register at the chimney is lowered. During this process of sweating, some metal is separated and gathers in the basin of the furnace. When the ore is thus uniformly heated, some fine charcoal is thrown into the furnace and mixed with the slag. The metal thus formed is tapped off, the heat raised, and then the slag is diligently stirred. When the charcoal mixed with the ore is nearly consumed, more is thrown in, and the slag and coal are turned over together by means of paddles, or iron bars flattened at one end. This operation of alternately throwing in fine coal, mixing it with the ore and tapping metal, is continued until nearly all of it is exhausted from the ore. The heat in the furnace is a dull red heat, kept up rather by means of the burning sulphur than the combustion of any fuel in the grate. When the metal is nearly extracted from the ore, the heat is gradually raised on it. At last some few shovels full of quicklime, with some charcoal, are thrown in, and this mixed with the ore, and to it a strong heat is imparted. This generally brings out all the metal which can be obtained, and which amounts to about 72 per cent. of the ore at the Western furnaces. The slag which is removed after the charge is exhausted, is subjected to re-smelting in the slag furnace. About 4 hours are required for one heat at a furnace; smelting about 4 tons of metal in 24 hours. Near Galena, Mo., about 1 cord of wood is used for smelting a ton of lead; the wages amount to $2 50, and general expenses about $2.

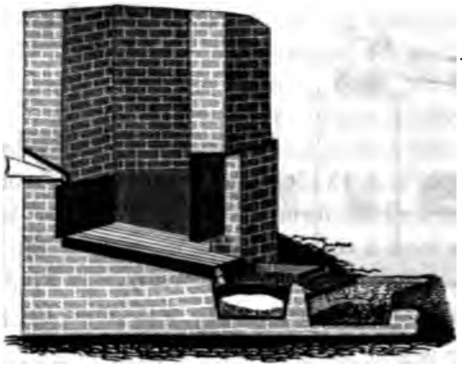
The blast furnaces in use for the reduction of galena, are about 6 or 7 feet high, and 12 inches wide. They are worked by a tuyere in the back of the furnace. The interior does not materially differ in form from a common cupel oven, with the exception of being square, and having an open tymp. In fig. 336 a vertical section of such a furnace is shown; it requires no particular description. The operation of smelting, which we shall describe hereafter, is very simple. In the Western States the furnace is fed with charcoal, of which 10 bushels are consumed for smelting 1 ton of lead; besides $\frac{1}{16}$ of a cord of wood. Three thousand pounds of ore furnish about a ton or 2,100 pounds of metal, which makes the yield 70 per cent. Three hands are required to attend a furnace. The expenses of smelting a ton of lead do not amount to more than $5 or $6, inclusive of charcoal. A furnace furnishes 1 ton of metal in 12 hours.

FIG. 336.



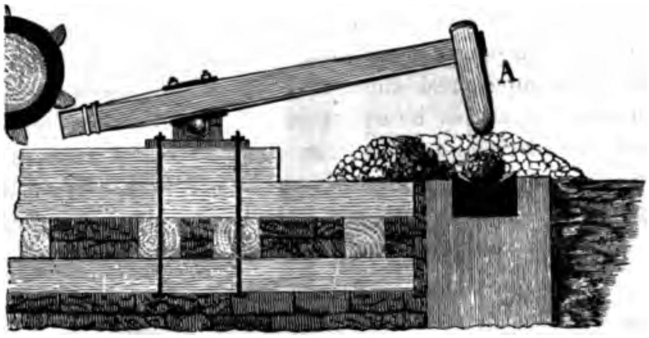
The slags obtained from the reverberatory and the blast furnace, and those from all ash furnaces of the lead region, are re-smelted in the slag furnace. This is a low furnace about 2½ or 3 feet high, and about 24 inches square, or the horizontal section forms an oblong of 22 by 26 inches. Fig. 337 represents a slag furnace. The hearth in which the reduction is performed, is constructed of cast-iron plates, so that no lead may be lost in dissolving the hearthstones. The front-plate is exposed to the fire, the others are covered by heavy charcoal dust; the bottom slopes very much, as is shown in the drawing. Some of these furnaces are not provided with iron plates; they are consequently much exposed to injury by the fused slag, and cause in consequence loss of metal. In front are two iron basins, one receives the melted lead and scoria as they issue from the furnace; the lead remains in the first, the scoria runs over the top of it into the second basin, and as this is filled with cold water, it is cooled, flies into small pieces, and is thus shovelled out and thrown aside. The slags before they are subjected to reduction in these furnaces, are either pounded in a stamping mill in order to recover grains of metal which may happen to be inclosed in them, or are simply broken into pieces of the size of a hen's egg, by means of a hammer or pounder. The yield of a furnace is equal to, and sometimes, by smelting rich slags, superior to that of the blast furnace; 2,500 pounds, and frequently more, lead is smelted in 12 hours. The slags obtained are by no means free from oxide of lead; it contains as much as 20 per cent. of metal. Charcoal is in general use as fuel in these furnaces.

FIG. 337.



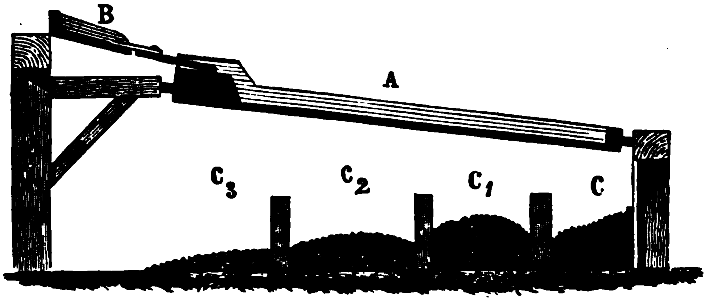
At the English mines the ores are subjected to a mechanical purification before sending them to the smelt-works. The crude ore is assorted by hand, after which it is subjected to grinding between fluted rollers, similar to those represented in fig. 338.

FIG. 338.



When the ore, or a part of it is so hard as to injure the hard cast-iron rollers, it is sent to the stamping mill. Ores which are required to be very fine are also stamped, after having been crushed between the rollers. Thus converted into sand, it is washed in order to remove gangue and adhering impurities. The crude pieces are, in some instances, sifted and washed before they are crushed. After the ore has been so far diminished in size as to be suitable for effectual washing, it is sifted into the tossing-tub, fig. 339, or into the jigging apparatus. This is a tub with water,

FIG. 339.



in which a round common sieve is moved by hand, and in directing that motion skilfully up and down the impurities are brought on the top of the ore. The separation of impurities is essentially effected by hand, the use of sieves and water merely assists this operation. The leading object in this case is to force water through the meshes of a sieve, in which a couple of inches of ore sand is contained; the water in passing through the stratum of ore will raise the light particles above the heavy ones, which finally form the lower stratum in the sieve. It is immaterial to the success of the operation if the water is moved, or the sieve with the ore is moved; the first plan has been successfully resorted to, and a pump made to drive water through stationary sieves. The impure residuum thus obtained, is subjected to washing in a cistern, simply by agitation with a shovel; or, the ore is washed in a short labyrinth. The most successful mode of separating the impurities from the crushed ore, is that by means of the sweep-table, shown in figs. 340 and 341. The operation on these tables has been described in Part Second of this work.

Fig. 340.

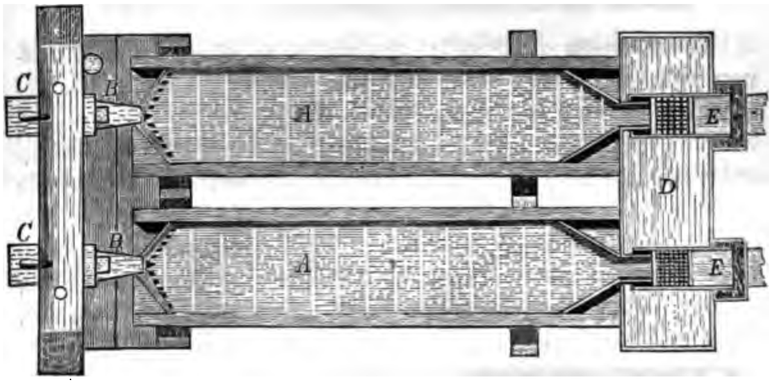
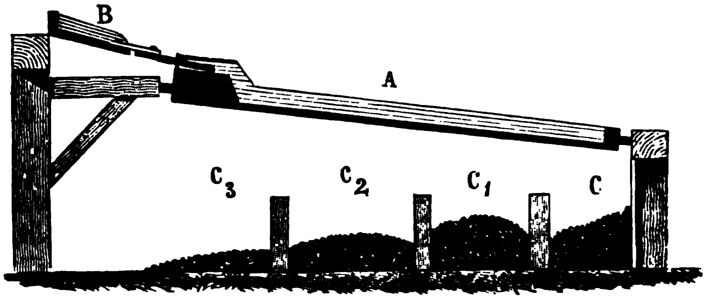
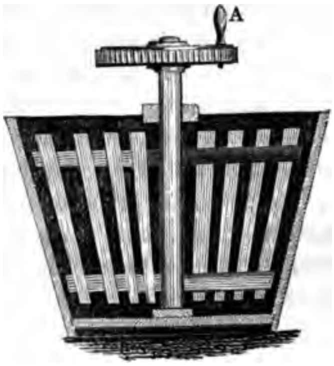


Fig. 341.'



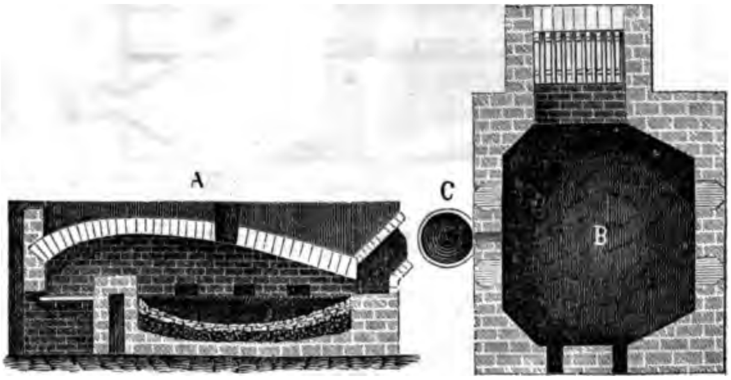
A machine generally useful is the dolly tub, shown in fig. 342. In turning the vertical shaft with its paddles, by means of the pulley A, or a winch, the ore and water in the tub are set in motion; the first on being suspended in the latter will settle soonest, and the lighter impurities afterwards. The separation may be accelerated by striking the sides of the tub.

FIG. 342.



The smelting of lead ores in England is almost exclusively performed in reverberatory furnaces. Fig. 343 A shows the vertical section of a smelting furnace, and B a plane of it. The hearth, which is about 12 feet both in length and width, is formed of slags and considerably hollow; it is about 24 inches from the doorsill to the deepest place. Its general slope is towards the basin C, where it is lowest.

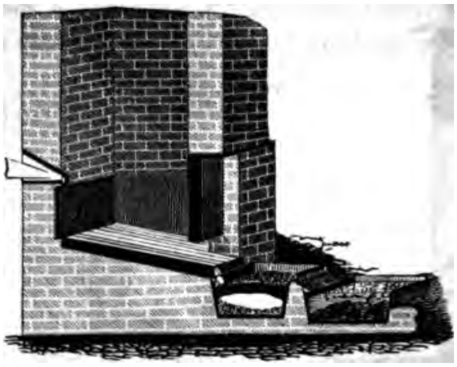
FIG. 343.



The operation in these furnaces is similar to that described above. When the hearth is formed by refuse, or slags of previous smeltings, and settled by heat, the ore is charged through the aperture in the top, to the amount of 20 cwt. at once. It is subjected for 2 hours to a gentle heat, so as to expel most of the sulphur; meantime all apertures to the furnace are closed. At the expiration of that time the furnace is opened, and the reduction of the ore gradually accomplished, by throwing in small charcoal, stirring the mass, and tapping the metal into the basin C. The slag which passes out with the metal is returned to the furnace, and worked with the other slags. When the ore is almost exhausted of its lead some quicklime is thrown in, a strong heat is finally given, and when all the lead which may be obtained is removed, the slags are drawn out and a fresh charge of ore is introduced. From 4½ to 5 hours are required for the extraction of the metal, after which the slags still contain from 20 to 25 per cent. of metal. From ½ to ¾ of a ton of inferior mineral coal is consumed in smelting a ton of lead.

In some parts of England, the blast furnace called Scotch furnace, fig. 344, is used for smelting lead ores. In that case the ores are, previously to smelting, roasted in a reverberatory furnace with a shallow or flat hearth. In roasting, about half a ton of ore is charged, gently heated and diligently stirred for two or three hours, so as to expel all or most of the sulphur. Roasted ore furnishes about twice the quantity of metal, in the same time that crude ore does. From one to two tons of metal are smelted in a furnace during a shift of 14 or 15 hours. The metal of this operation is generally very pure, and of a superior quality.

Fig. 344.



The rich slags produced either in the reverberatory, or in the blast furnace, are resmelted in the slag furnace, as described above.

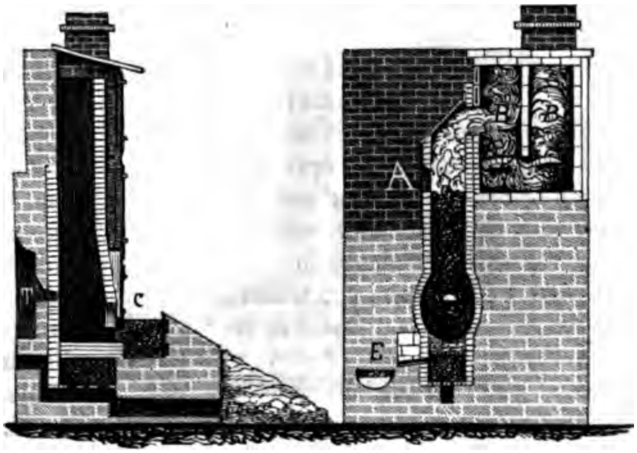
In France the smelting of lead ores is in some places performed in reverberatory furnaces, with the assistance of iron ore. When the crude ore and slags in the furnace are so far exhausted of their metal, as to yield no more lead by the addition of small charcoal and increased heat, the smelter throws into the furnace some stamped and washed sparry iron ore, instead of lime; this amounts to about 10 per cent. of the lead ore primarily charged.

This addition stiffens the slag; which is now withdrawn from the furnace, and subjected to resmelting in the slag-hearth. Nearly all the lead is obtained from the slags in this last operation.

In Germany generally the ores are purified by hand; washed, stamped, and washed again, and roasted with salt, or iron, or iron ore.

The roasted ore is smelted in blast-furnaces, which are from 12 to 14 feet high. The construction of such a furnace is shown in fig. 345. The front or tymp of the furnace is walled up with bricks, which are temporarily put in with clay mortar. The width of the furnace is from 12 to 14 inches square or oblong. The hearth, or bottom of the furnace, is formed of a mixture of loam and charcoal dust firmly rammed in. The basin outside of the tymp contains the lead which is tapped off by opening a tap-hole communicating with its bottom. The slags are conducted on a slope to a basin wherein they are accumulated for re-smelting.

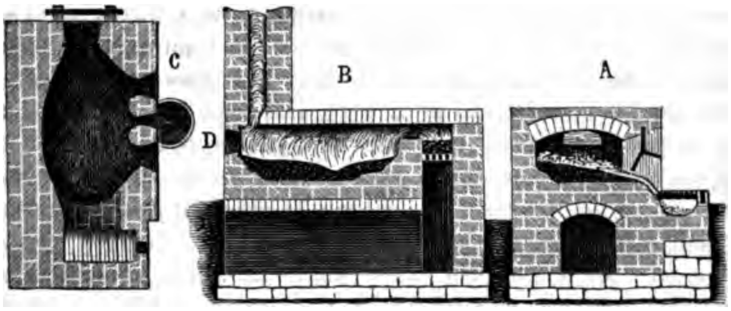
FIG. 345.



This furnace may be fed either by charcoal or coke; the latter requires a blast somewhat stronger than the former, but in no case more than $\frac{1}{2}$ or $\frac{3}{4}$ pound pressure. A fan-blower is sufficient for charcoal; coke requires a cylinder blast. Coke operates as well as charcoal, and yields equally as much and as good metal from the ore as the latter. In working the furnace, it is warmed previously to charging ore, which is mixed with fluxes, such as litharge, iron ore, calc-spar, fluor-spar, or other substances. Fuel and ore are charged alternately, as at any other blast furnace. The blast is gently urged in case charcoal is the fuel. The metal, or metals, gather below the tuyere in the basin of the hearth, and separate into various strata; pure lead and all the silver is at the bottom; upon this there is a stratum of alloys of lead and other metals, and on the top a stratum of matt which is covered by the poor silicious slags. The latter may be carefully drawn off and removed without drawing any matt or metal. When the matt reaches so high as to admit very little slag on its surface, the blast is stopped, the tuyere temporarily closed up, and the metal tapped into the basin. As the purest metal is below the matt, and the furnace tapped at the bottom, this flows out first; and when the drawing is not hurried, it may in some measure be separated from the impure metal and the matt on its top. Generally the metal is tapped from the furnace at intervals of 8 hours, and very little is left in the furnace. When it is thus removed, the hearth is cleared of adhering cinder by opening the tymp, and the operation goes on as before. A continual blast of six days and nights work may thus be made, after which the furnace is cooled and thoroughly repaired. In the basin before the hearth, into which the metal has been tapped, and which is kept well heated, the metals separate again into different strata, which may be obtained after removing the cold crust of slags, as it forms on the surface. As the purest lead is at the bottom of the basin, it is ladled out after the upper strata of alloy and matt have been removed. In this operation the poor slags are thrown away, and the rich ones and matt are resmelted with the ore.

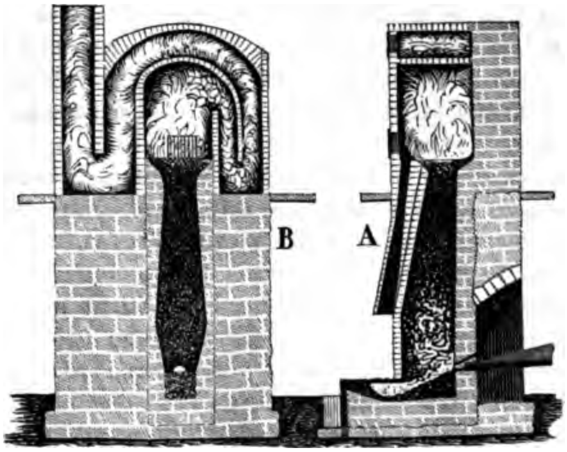
The best, and purest kind of lead is smelted in a peculiarly constructed reverberatory furnace, of which fig. 346 A, shows a vertical section across the furnace. We observe here the strongly sloping hearth. B is a longitudinal section, and C shows a plane of hearth, grate and charging door D. The hearth is formed of loam, about 12 inches thick, into the surface of which a layer of finely broken slags, about 4 inches thick, is firmly pounded, and cemented by heat. The basin of the hearth is about 6 inches deep; towards both bridges it rises considerably more. The hearth of the furnace is about 12 feet long, and 8 feet wide. Wood is used as fuel.

Fig. 346.



The operation in this furnace is similar to that described above, for other reverberatories. The ore is successfully sweated, roasted, and reduced. The slags which remain after that operation are reduced in the blast furnace. In front of the furnace, as we have stated before, is a cast-iron pan, or kettle, into which the lead is tapped, and from which it is ladled into the pig moulds. In these pans very large crystals of lead may be obtained, when the metal is suffered to cool slowly.

Fig. 347.



At the Hartz mountains, in northern Germany, galena is reduced by the assistance of iron in blast, or elbow furnaces. When constructed for using coke, these furnaces are very low, or not more than 3 or 4 feet high; for charcoal they are from 18 to 20 feet high. Fig. 347 shows at A, a vertical section of ore through the tuyere. B is a vertical section seen from the front. The furnace is chiefly constructed of granite, or sandstone. The hearth is formed of fine coal and clay. The tymp is of common brick. The interior is about 2¼ feet by 15 inches at the tuyere; the mouth—top—is 15 inches wide, and round. On the top of the furnace is a labyrinthic succession of chambers, as shown in B, into which the dust from the ore, or the oxides of the volatile metals are condensed. The mouth is funnel shaped to prevent the deposition of volatile metal near or below the mouth of the furnace. A hood formed at the tymp, and which communicates with the condensing chamber, draws in the vapors of those metals which escape at the tymp.

The ore which is smelted in these furnaces is always extremely well prepared, pounded and washed. Instead of iron ore, granulated cast-iron is used with success. The ores may be very impure, but the lead is always obtained in great purity.

Theory of smelting Lead Ore.—The reduction of lead ores is extremely simple. In all instances of smelting, a considerable loss of metal is experienced, which has been the cause of a close examination of the process, and we may assert, that no metallurgical operation is more thoroughly and scientifically known than the reviving of lead. This metal is in most instances the bearer of silver, the bulk of which is obtained from lead ores. In order to investigate the cause of the loss in lead metal, and also a suspected loss of precious metal, much labor and ingenuity has been bestowed on this subject.

In the smelting of crude galena in a reverberatory furnace, the sulphuret, is at the commencement of the operation, deprived of a part of its sulphur by heat; metal is formed, and as oxygen finds access to the ore, oxide of lead, and consequently sulphate of lead is also formed. The proportion of these substances depends of course on the degree of care bestowed upon the process. When after two hours the roasting of the ore is so far completed as to admit of its reduction, the heat is raised so high as to form a pasty mass. Oxide of lead and sulphuret of lead now mix completely and form metal, sulphuret, and sulphate, from which mixture the metal parts by force of gravitation. In mixing carbon with the slag the sulphate is reduced to sulphuret, which is again deprived of its sulphur by heat. Thus, by alternate oxidation and reduction of the ore, a certain amount of metal is abstracted. The revival of lead from the slag, causes it to be more refractory at the end of the operation than it was at first, because the sulphuret or the oxide of lead, which was the cause of its fusibility, is chiefly removed. When the slags are so pasty as to inclose grains of metal which have not the power of separating by gravity or cohesion, they cannot yield any metal although the whole of it may be revived. In order to obtain all the metal from the slag it ought to be at least as fluid as the metal itself, at the same degree of heat. Such a slag is not easily obtained without oxide of lead, or sulphurets of other metals. Salts of any kind, such as fluorides, chlorides, and sulphates, form the best auxiliaries in this operation; and if present only in a small quantity they are of service. Lead, bismuth, antimony, and in fact all the fusible metals will readily separate from other matter than metals, in virtue of their gravity and cohesion, but it is a necessary condition of their separation that the matter with which these metals are combined should be fluid. The metal cannot separate from a dry slag, an agglutination of its particles is necessary before it can subside.

A fluid cinder is necessary not only for the agglutination of the metallic particles, but also for their production. When a dry or pulverulent mixture is mixed with carbon, oxygen may be abstracted from it by the carbon; but as the newly-formed particle of metal is exposed to the influence of oxygen—which it will absorb from the products of combustion if it cannot obtain it in another form—it will oxidize as quickly as it is reduced. If metallic oxides, or sulphurets and slags, are fluid, the addition of carbon to the mixture will deprive the oxidized metal of oxygen; and if the metal as well as the slags continue to be fluid, the latter will protect the first against oxygen. The fluidity of the slags will also admit of the subsidence and gathering of the metallic particles.

In smelting galena in a reverberatory, we deprive the slags gradually of the means of fluidity by abstracting that metal from them which has been the cause of their fusibility. This abstraction can be carried only to a certain point. When the slags cease to be fusible at the heat by which the metal melts, they must cease to furnish metal any further, however much may be contained in them. We perceive, therefore, very readily, that the quantity of metal retained by the slag depends entirely on its fusibility, and not on its composition. Lead, like the precious metals, separates easily from all other matter, and thus far the composition of the slags has little effect on its quality. If in operating on galena, fluxes can be introduced which continue the fluidity of the slags at a moderate heat, all the lead, even the last particle of it, may be obtained.

The fluidity of slags depends as well on heat as on their composition; we may continue the fluidity of a slag by increasing the heat; this, however applicable with some metals, is not the fact with lead. When the heat on metals is raised beyond a certain degree, they evaporate. In any smelting operation, therefore, it should not exceed that degree. Metallic lead, and especially oxide of lead, sulphuret and salts of lead, are very volatile, and a strong heat on them must be avoided. It must be, therefore, the practice to smelt lead by as low a heat as possible; and in order to accomplish this, a mixture of ore must be prepared which affords a fusible slag without lead.

Lead combines very readily with other substances under certain conditions, and in most instances in definite proportions. Iron will combine with sulphur in all proportions, but not so lead. There are various combinations of lead and sulphur, which, when exposed to heat, form the combination which we recognize in galena. If less sulphur is present, metal and sulphuret are formed. This accounts for the revival of pure lead from galena that is partially roasted. In the composition of reverberatory and blast furnace slags, we find the means of detecting the true conditions under which lead is smelted most profitably.

A slag which had been deprived of its metal by a long-continued operation in the reverberatory—16 hours' work—contained still 13 per cent. of oxide of lead, 53·5 oxide of iron, 11·5 barytas, and 5 sulphuret of lead; also 17 silex. This shows that the last particles of sulphur will adhere to lead, when all other substances are oxidized. A reverberatory slag entirely free from sulphur, contained sulphate of barytas 51, sulphate of lime 10·5, fluoric acid 1·5, protoxide of iron 3, and oxide of lead 34. A slag obtained from impure galena, that is, an ore from which heavy spar could not be separated, was composed of 30 sulphate of lead, 24 sulphate of barytas, 5·6 gypsum, 8·5 fluoric acid, 14·7 carbonate of lime, 2 sulphuret of lead, 5·6 protoxide of iron, 8 oxide of zinc. A very fluid slag which flowed off with the metal, contained sulphate of lead 9, sulphate of barytas 30, sulphate of lime 33, fluoric acid 13·6, lime 8·8, oxide of iron 2, oxide of zinc 2. This contains the least lead, and large quantities of alkaline salts; all the alkaline earths are combined with some acid, which renders the compound fluid.

The last-mentioned slag is produced from crude galena which has been merely freed by hand from impurities, and for these reasons we invite attention to it. It shows a very rational operation, and one most suitable for our country. The ore is charged in the furnace in the common manner, and reduced so far as it will furnish metal. When the slag becomes too stiff for yielding metal, some finely-pulverized fluate of lime is thrown in and mixed with the mass. This renders the barytas and gypsum fusible, and the reduction of galena may take place. So long as the fluidity of the slag is continued, lead is formed. To render this operation profitable, fluate of lime should be used in a considerable quantity; but as this cannot be obtained always, we propose the substitution of chlorine for fluorine, which possesses in as high a degree as the latter the quality of fluxing sulphates. In this instance, gypsum and common salt may be pulverized together when damp. These form a very fluid slag with barytas, lime, iron, and other metals.

The following reverberatory slag shows that lead can be removed almost entirely from the ore, in oxidizing the mixture completely. A slag from zinc ore contained 64·5 protoxide of iron, 2·5 oxide of lead, 1 oxide of zinc, 2·5 alumina, and 29·5 silex. The iron and silex here form the slag. It must be observed that in precipitating all the lead from a slag by means of iron, the metal will contain much iron and be otherwise impure. When an ore contains much zinc there is hardly any other profitable way of smelting it than to flux by means of iron, either with iron ore or pyrites; all, or most of the zinc, remains then in the slag.

The slags of blast furnaces differ somewhat from those of the reverberatory, in containing more silex, and, in most cases, less lead. A slag which was formed at a moderate heat, and considered as exhausted of lead, contained 34·4 oxide of iron, 6·6 oxide of lead, 7 lime, 9 sulphuret of iron, a little manganese and oxide of zinc, and 34·8 silex. A slag from an argentiferous galena contained protoxide of iron, 45·4; magnesia, 11·2; sulphuret of iron, 2; alumina, 3·9; and silex, 36·3. The following proportions show that a large quantity of lime is of no advantage: protoxide of iron, 25; lime, 24; zinc, 10·6; oxide of lead, 3; alumina, 7; silex, 28·5. The following is a profitable slag: protoxide of iron, 34·8; oxide of zinc, 6·8; oxide of copper, 2·4; manganese, 7; lime, 6·6; magnesia, ·6; oxide of lead, 2; sulphuret of iron, 12: alumina, 8·4.

When ores are exposed to a low heat, they hardly enter into any combination with silex, and of these the oxides only. Sulphurets, sulphates, chlorides, fluorides, and, in fact, all other metallic compounds, do not combine with silex; it is only after all other matter is evaporated that the oxides unite with that acid. We may smelt lead to perfection without forming any silicate, but this requires the presence of a large quantity of chlorine, fluorine, or some other permanent acid. In roasting the ores before smelting we are deprived of the advantages resulting from the fusibility of the sulphurets and acids, and are compelled to form silicates, because those substances which form a fluid slag in the low heat of a reverberatory, evaporate in the heat of a blast-furnace and are lost. When it is in our power to form a fusible slag, either by means of fluates or chlorides and sulphates, it is more profitable to smelt in a reverberatory than in a blast-furnace, and precipitate the lead to within a few per cent. in the first and only operation. In this instance the ore needs no crushing and expensive washing, a removal of the coarsest pieces of quartz and of the loam is the only labor necessary to be performed on it. The presence of quartz will not influence the result, because when other acids are present it does not enter into combination. If no materials are at hand to form a fusible slag, either by natural or artificial means, then it is necessary to roast the ore and smelt in the blast-furnace. In this instance, the ores must be roasted, because the sulphurets are very volatile, and will not resist the heat of that furnace. The most profitable flux is the protoxide of iron. Lime or magnesia, and other alkaline earths, do not form sufficiently fluid slags to be used profitably.

When circumstances render it necessary to smelt in blast-furnaces, the operation ought to be conducted in such a manner as to obtain all the lead at one smelting. This appears sometimes to be difficult, but it is not so where cheap iron ore can be obtained in sufficient quantity. When a slag or ore is to be exposed to smelting in a blast-furnace, it ought to be thoroughly oxidized; because if any sulphur is left in it, even in the form of sulphate, lead and zinc are the first to evaporate. Lime does not remove sulphur, but combines with it, like all other alkalies. Iron, because it absorbs sulphur, and as easily parts with it, is the most suitable substance to mix with the sulphureous ore for the purpose of oxidation; it forms a fluid slag at quite a low heat with silex, and is thus far the best flux in the blast-furnace. Manganese serves equally as well as iron, and may be substituted for it; but no other metallic oxide can be substituted for these two.

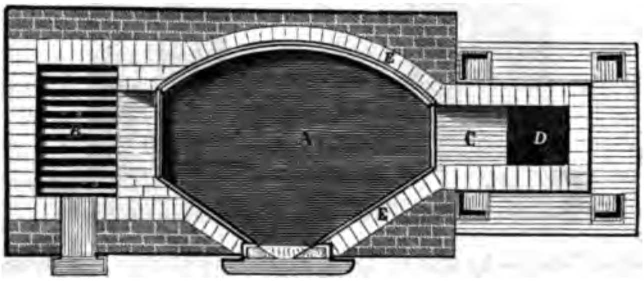
When sulphurets of lead are roasted in the air, they are never entirely liberated from sulphur; the most carefully roasted lead ore contains sulphur. Galena roasted with extreme care, in a heap, contained oxide of lead, 18; sulphate of lead, 86; sulphuret of lead, 10. The same galena, roasted during 7 hours in a reverberatory, formed metallic lead, and the roasted ore powder consisted of oxide of lead, 30; sulphuret of lead, 46, metallic lead, 17; iron oxide and silex, 7. When other metals are present besides lead, such as iron, zinc, and others, they are oxidized before all the sulphur is removed. A persevering roasting of 10 or 12 hours, in a reverberatory furnace, will remove much of the sulphur, but from 8 to 10 per cent. of sulphate of lead remains in all instances. The presence of a large quantity of silex, say 25 per cent. of the ore, is the best means for the removal of sulphur. From such ore the last trace of sulphur may be removed in the reverberatory, or in roasting it in the open air. It would not make any difference by what means sulphur is removed in roasting, and silex might serve quite as well as iron, if it could be removed advantageously before bringing the ore or slag into the blast-furnace.

In practice at the furnaces, we find the above principles operate under forms modified by local circumstances. The smelters at a reverberatory furnace alternately cool and heat the furnace, in order to oxidize and reduce, by means of granulated coal. A fluid slag cannot quickly oxidize; it is like melted metal in this respect; there are no points of contact for the oxygen. The drying up of the slags, by cold or drying flux, such as lime, facilitates the oxidation of the sulphuret. The best plan is to run the metal and slags out continually, the first into a heated iron pan, the latter over damp charcoal-dust. This mode of operation causes oxidation quicker than any other. When the slag is cooled, it may be recharged or reserved for the slag-furnace. Slack coal should never be mixed with the slag for reduction; a granulated coal assists in forming large globule of metal; it affords points of oxidation for the slag, and does not stiffen it so much as fine coal. When litharge is reduced in a reverberatory, it does not work well if both coal and litharge are fine; this is not from want of affinity or other secret causes. The powdered mass does not admit of the formation of a large globule of metal, or of motion in the fluid metal, which is necessary for agglutination. And as oxide of lead, particularly when mixed with a refractory substance, does not melt at so low a heat as metallic lead, the whole mass must be heated until the mixture of oxide and coal begins to become fluid, and admits of the subsidence of the metal. Litharge is easily reduced in the reverberatory. A charge, consisting of one ton of litharge, may be smelted in 1½ or 2 hours, when in a granulated form, but when finely ground litharge or fine coal is used, twice as much time is required. When the heat must be urged so high as to melt the litharge, the process is slow. We find the principle of the operation here to be different from that of smelting ore; if, in the latter case, we work the ore dry, as litharge, we produce but little metal. The cause of this is plain: there are impurities and metal in close contact in the ore, and no large globule of metal can be formed, because the foreign matter interposes between the particles of metal.

The conditions under which successful smelting may be performed are therefore very plain. A fluid slag is in all cases required where impure ore is to be smelted; pure ore, or litharge, may be worked more dry than impure ore. Fusible slag may be produced by a variety of means, of which heat is the most available, but not the most profitable. High heat causes a loss of metal by evaporation; it brings foreign metals into the lead, which are injurious to its quality. Lead, and in fact all other metals, ought to be smelted at the lowest heat by which they can be melted. A low heat or quick work, will produce the best metal, in all instances, and as that kind of work demands less fuel and labor, too much attention cannot be bestowed on this subject. Fusible slag should be formed by means of fluxes, not by heat, which will, in most instances, remove those ingredients which cause fluidity. Protoxide of iron, which is most successfully formed of powdered hematite ore and carbon, forms readily a fusible slag, in the presence of chlorine, fluorine, sulphuric, phosphoric or any other acid; but these acids are soon evaporated by a strong heat.

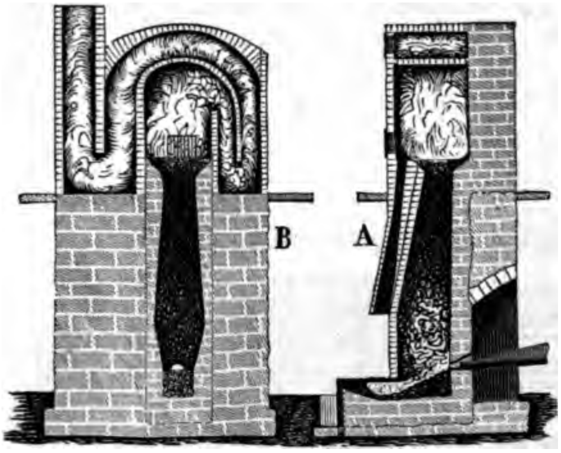
Smelters dislike the use of much iron in a reverberatory, as well as in the blast-furnace, because in its most fluid condition it acts upon the stones, bricks, and slags, of which the hearth is formed, and causes their premature destruction. When the work is done on a fine charcoal or coke hearth, in the presence of much iron, it is reduced with the lead, and impairs its quality. We recommend for these reasons, for smelting lead, the application of cooled boshes, and cold cast-iron bottoms, such as are used in puddling furnaces, fig. 348. In the slag hearth and blast-furnace, iron plates are generally used below the tuyere, and are lined with clay or coal-dust, but both these materials for linings are injurious as well to the quality of the metal as to the yield. There cannot be any disadvantage in surrounding a slag hearth with cooled iron plates, similar to a run-out fire for refining iron. A little more fuel may be used in smelting, but a more fluid cinder can then be employed than in any furnace, which of course tends to economize fuel, and causes a purer article of metal. Furnaces of this kind were used in the State of New-York, and worked successfully. The hearth plates were cooled by the blast.

FIG. 348.



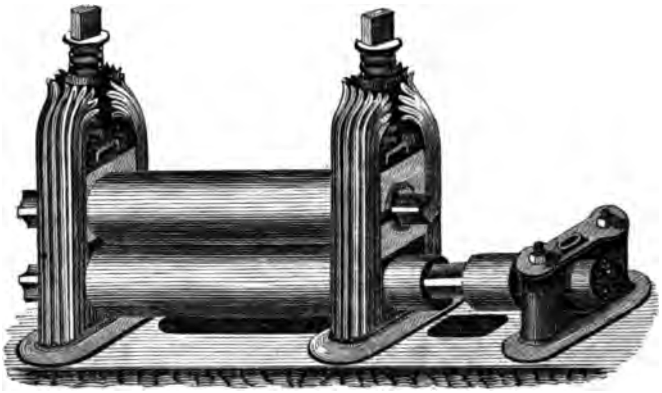
Lead Smoke.—At the smelting furnaces, particularly at those where the operation is performed at a high heat, a white smoke is thrown out at the tymp, or at the top of the furnace. This may be gathered in condensing chambers, as shown in fig. 349. Similar chambers may be annexed to reverberatories, as will be shown hereafter. This white smoke contains those metals which are in the ore. A reddish dust from a reverberatory contained, 11 oxide of lead, 60 sulphate of lead, 2 arsenious acid, 15 oxide of zinc, 12 oxide of iron. When there is much zinc in the ore, and it of course evaporates, a large quantity of silver is carried away by it. Iron and coal are generally the coloring matters in the body of these deposits. It is always found to be chiefly oxide and sulphate of lead.

FIG. 349.



Sheet Lead.—As this metal is extremely pliable and fusible, it may be converted into a variety of forms with great facility. Sheets of $\frac{1}{12}$ of an inch thick, may be cast of a considerable size. The operation is performed on a table covered with sand or cloth; this was formerly the only mode of forming them. At present, sheets of any size, 8 or 10 feet wide, and of considerable length,

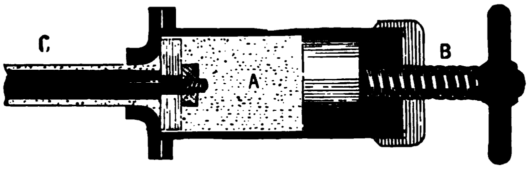
FIG. 350.



are rolled between rollers, of a similar construction as shown in fig. 350. In order to prevent their wrinkling, to which they are subject, in consequence of softness of the metal, the rollers are provided on each side with a long apron, upon which the sheet may move; and in order to diminish the friction between the sheet and the apron, it is made of a succession of wooden rollers, parallel with the main rollers. The lead for sheets is cast in a stone mould, about 2 or 3 feet square. Pipes are formed by casting a heavy pipe, about 3 feet long, and from ½ to 1 inch in thickness over a mandril, and by drawing this cast pipe through a succession of decreasing apertures in a drawing bench, a pipe of a certain thickness and a bore of the size of the mandril is formed. In this manner a pipe of only a limited length can be drawn out.

A more convenient and cheaper process for forming lead pipe, is performed in drawing the pipe directly from melted lead. When a cast-iron cylinder, smoothly bored, is provided with a piston, which is movable, yet fits closely, and one end of the cylinder is closed with a bottom having a round hole, any plastic matter forced through the hole will assume its form. If there is in the aperture of the bottom a solid centre so inserted as to form an opening of the form of a ring, any matter which may be pressed through the opening will form a pipe. Fig. 351 shows the principle of this machine. When the cast-iron cylinder is gently heated, so as merely to melt the lead in the space A, and a pressure is applied at the piston-rod B, the fluid metal will be forced out at C, and form a pipe. That part in which the pipe is formed is cooled artificially. Pipes may be formed of considerable length in this machine. It depends on the capacity of the melting apparatus. The pipes thus formed are very smooth, and uniform in thickness. A similar apparatus has been proposed and patented for making sheet lead. When the cylinder is 2 feet or more in diameter, and the core which forms the bore of the pipe is nearly as wide as the cylinder itself, so that a space of the thickness of the sheet is formed between it and the cylinder, any fluid lead

Fig. 351.



which is pressed through will form a wide pipe; which subsequently is slit open and becomes a sheet.

CHAPTER VII.

Copper.—Pure copper is of a light reddish-brown color and of a high lustre. It is one of the most ductile and malleable metals. Sheets and wires may be formed of it with the greatest facility. Its fracture is similar to that of tin, or wrought-iron. After hammering, its appearance is silky and its lustre seems increased. Its specific gravity when cast is 8·91, in wire 8·93 to 8·94, in sheets 8·95. Copper fuses at 1996°, and absorbs oxygen from the air when that is accessible, so as to reduce its specific gravity to 8·7 or 8·8. It may be welded when pure. Heated to fusion it absorbs oxygen and oxidizes the surface, and becomes covered with a black crust; by a strong heat in the muffle it may be converted into suboxide altgether. Heated to a high white heat, it burns with a light-green flame. In dry air, copper is unchangeable; in moist air and in that containing carbonic acid, sulphuretted hydrogen, or other acids, it becomes dark-green and assumes a bronze color.

Ores.—Copper ores form an extensive class of minerals, which it is difficult to distinguish by mere ocular inspection. However, at all copper veins, oxides more or less green are found on the surface, which, in connection with other marks, form a sure indication of the presence of copper ore.

Native Copper.—This occurs in crystals disseminated through rocks, usually massive, in the form of scales; and compact masses ramifying the rock in all directions. It is found in beds, veins, and detached masses and grains, in solid rock and imbedded in loose soil. Most of the copper ore veins contain metallic copper. Native copper is distributed over the whole surface of the globe, but nowhere is it found more generally and in larger masses than in the United States. It occurs in New England, New Jersey, Pennsylvania, Virginia, and North Carolina; and in the greatest abundance at Lake Superior, near Kewenaw Point; at the Ontanawgaw River, and other localities of that region. Masses of native copper, of 80 tons weight, have been excavated in the Cliff Mine at Lake Superior. The copper occurs here in trap or sandstone rock, or near their junction, in the form of injected veins. The origin of the metal appears to be from veins, whose ores have been reduced by the heat of the volcanic rocks.

The usual copper ores are sulphurets and oxides; the former are more abundant than the latter. Copper is also found combined with arsenic, selenium, antimony, iron, silver, and acids.

Sulphuret of Copper.—This occurs in various forms. Copper glance is one of the varieties frequently met with in copper ore veins. Its specific gravity is 5·5, lustre metallic, color and powder black or lead-gray, fracture conchoidal. It occurs frequently massive, but also granular and in fine powder. This ore is found in Connecticut, New-York, Virginia, Maryland, and other States of the Union, and is profitably mined in many localities. When pure it consists of 77·7 copper, ·91 iron, 20 sulphur, and some silica.

Copper Pyrites, or Yellow Copper Ore, is the most common sulphuret used in the smelt-works. It is rather light; its sp. gr. 4·1 to 4·3, color brass-yellow; it is subject to tarnish in the air, and is then iridescent. It forms a greenish-black powder, of sharp edges. It always contains much iron, and is on that account highly esteemed in the smelt-works. Its composition in crystals is 34·40 copper, 30·47 iron, 35·87 sulphur, and sometimes a little quartz. It is often largely mixed with iron pyrites—in fact, so far that the latter fills the vein—and there are either only traces, or but a small per centage of copper ore in the mixture. Copper pyrites is the principal ore of the English smelt-works, as well as those of this country, along the Atlantic coast. The bulk of copper is manufactured of this ore. In the United States it occurs at Southampton Lead Mines, and other places in Massachusetts; in Vermont, New Hampshire, Maine, New-York, New Jersey, Pennsylvania, Maryland, Virginia, and the gold region generally; it also occurs in Wisconsin, Missouri, and Iowa—in fact, almost every State of the Union contains this copper ore. Although copper pyrites is found in great profusion, the ore is always poor; it does not often yield more than 12 per cent., and frequently the body of a vein does not often contain more than 2 per cent. of copper. When it can be brought at reasonable prices to the smelt-works it is valuable, for it is much liked in the furnaces. It yields its copper with great facility, requiring but little labor and the use of little fuel. The contents of copper in an ore of this kind, may be estimated by an experienced person on mere inspection. A bright yellow color and softness, indicate a rich ore; a dull yellow, or pale yellow and great hardness, are indicative of a poor ore. Copper pyrites is readily distinguished from iron pyrites by its inferior hardness—it may be cut by a steel point or a knife; this is not the case with iron pyrites, which will strike fire with steel, but not so that of copper. Spangles of this ore, which frequently occur in the gold ores of the Southern States, are distinguished from those of gold by their brittleness.

Gray Copper.—This is a variety of sulphuret of copper, which, on account of its interesting composition and its good behavior in the furnace, is much liked by the smelter. It occurs massive, granular, in a fine powder, and also crystallized; it is of a steel-gray, often iron-black color; its sp. gr. is 5·1, and it is rather soft and brittle. Ore of this description occurs in New Jersey and Pennsylvania; and a vein, 18 inches in thickness, is stated to have been opened at Lake Superior. The composition of this ore varies greatly, but on an average it contains from 25 to 40 per cent. of copper, from 20 to 30 of sulphur, and nearly as much antimony. This forms the bulk of the ore; but it contains besides, arsenic, zinc, silver, quicksilver, lead, platinum, and other metals.

Oxide of Copper.—Red oxide of copper is hardly used as an ore. It occurs as an accidental admixture with other ores—particularly with native copper. It is of a cochineal-red color, occasionally crimson red, or various shades of red. It occurs in the form of a powder, granular, massive, and crystallized. Other varieties of oxide of copper, such as the black oxide, are of no practical interest.

Silicate of Copper.—This occurs chiefly as an accidental admixture of other ores, and is a constant companion of them. It is green, varying from the emerald-green of the dioptase to the sky-blue of the chrysocolla; when impure, it is brownish or of an earthy color. It is most frequently translucent, not often opaque. Its sp. gr. is 2 to 2·2. A specimen from New Jersey contained 42·6 oxide of copper, 40 silica, 16 water, and a little iron. The ore contains frequently carbonic acid.

Carbonate of Copper.—Malachite, green carbonate of copper. This is similar to the above. It is an ore which accompanies other copper ore. As an ore of copper it is of little consequence, however rich it may be, because not much of it is known to exist. Its composition is 71·82 protoxide of copper and 20 carbonic acid, 18·18 water.

Besides these ores of copper, there are sulphates, phosphates, arseniates, chlorides, and others, all of which are of little practical interest; they are companions of other copper ores, and occur only in small quantities.

Alloys of Copper.—Of all other alloys, those of copper are of most interest. Copper alloyed with arsenic is extremely white, similar to silver; but it is brittle and hard. With zinc it forms brass; and the amount of the respective metals determines the variety of this alloy. Pure copper does not form close and compact castings. Instead of pure copper, about 99 of copper and one zinc are considered pure cast-copper. Zinc is introduced by adding about 2 ounces of brass, poor in copper, to every pound of copper. This quantity may be varied from ½ an ounce of brass to 3 ounces for every pound of copper. Gilding metal consists of 1 to 1¼ ounces of zinc to 1 pound of copper; it is of a bronze color. Red sheet is 3 ounces of zinc to a pound of copper. Manheim gold, pinchbeck, 3 to 4 ounces of zinc to a pound of copper. Ordinary brass of a red color, for being soldered, contains 6 ounces of zinc to a pound of copper; 8 zinc, 16 copper is a fine brass. Any proportion between 50 zinc, 50 copper, and 37 zinc, 63 copper, will laminate well and make good sheets. Common brass is 50 copper, 50 zinc. Solder may be made by melting brass, and casting it through a broom or fagot of brushes, into a tub of water. Or, the whole metal may be cast into iron moulds in the form of small cubes, of about one or two pounds each. When these are gently heated, nearly to melting, they may be broken up into small fragments by a smart blow of a hammer after placing the hot metal on an anvil or a thick cast-iron plate. It is stated that 50 copper to 52 or 58 zinc forms a dark-colored metal, which on dipping forms a gold-colored metal —Mosaic gold. Zinc 32 to 16 copper is a bluish-white, brittle metal, which may be pounded in a mortar. Zinc 8 and 1 copper, forms a white metal little differing from zinc except in tenacity; this alloy is stronger than pure zinc.

Copper and zinc appear to mix in all proportions, and the extremes of both assume the characters of the principal metals. The red color of copper is blended by the white of zinc to all shades from red to white. In forming brass by melting the two metals together, a heavy loss of zinc, which varies from $\frac{1}{10}$ to $\frac{1}{3}$, is always experienced. The best plan of smelting brass may be to melt the copper in a blacklead pot first, dry and heat the zinc near to the melting-point, and drop it gradually, in small pieces, into the copper, when the latter is not hotter than barely to continue fluid. The loss of zinc is then a permanent amount for each melting and re-melting, provided heat and time are equal. When the surface of the hot metal is covered by fine charcoal, which is prevented by renewal from burning, the smallest loss of zinc is sustained. Tombac consists of 85 copper, 15 zinc; prince's metal 75 copper, 25 zinc; fine brass for turning, 66 copper, 32 zinc, and 2 lead.

Copper and tin form another most interesting series of alloys: 20 copper and 1 tin is a flexible, tenacious alloy, good for nails and bolts; 9 copper, 1 tin, was ancient bronze—7 to 1 is hard bronze; the addition of a little zinc improves this article. Soft bronze, which bears drifting, rolling, and drawing, is generally composed of 16 copper to 1 tin; 12 copper to 1 tin is metal for mathematical instruments; 8 to 1, bearings for machinery; 9 to 1, a very strong metal; it may be considered the most tenacious of this series. Copper 5 to 1 tin, is very hard, crystallized, good for hard bearings in machinery. A soft metal for bells is formed of 3 tin, 16 copper; 7 tin, 32 copper, is for Chinese gongs and cymbals; 1 tin, 4 copper, is for house bells; 9 to 32, large bells. Speculum metal ranges from 1 tin and 2 copper to equal parts of both metals. Ordinary bronze is 78 copper, 17 zinc, 2·5 tin, 2·5 lead. Large bells are cast of 80 copper, 6 zinc, 10 tin, 4 lead. A very fine large bell consisted of 71 copper, 26 tin, 2 zinc, 1 iron. A good average bell composition is 75 copper, 25 tin: 90·5 copper, 6·5 tin, 3 zinc, is an imitation of gold; 91·4 copper, 5·5 zinc, 1·4 lead, 1·7 tin, composes bronze for large statues. Copper 80, tin 20, is common statue bronze; 92 copper, 8 tin, is bronze for medals; 85 copper, 14 tin, 1 iron, is the composition of ancient weapons. Copper 62, iron 6, tin 32, is the composition of ancient mirrors.

The melting together of tin and copper is less difficult than that of zinc and copper, because tin is not so liable to evaporate as zinc, and little metal is lost. The appearance of the alloy may be improved by covering the melted metal with about one per cent. of dried potash; or, which is better still, a mixture of potash and soda. This flux has a remarkable influence on the color, and particularly on the tenacity of the alloy. The former becomes more red, and the latter stronger. The scum forming on the surface by this addition ought to be removed before the metal is cast. Tin and copper are liable to separation in cooling; this can be prevented, at least partly, by turning the mould containing the fluid metal, and keeping it in motion until it is chilled.

The ancients manufactured their tools of copper, and hardened them as we harden iron. This art appears to have been understood over the whole world, for the Asiatic nations, Africans, and Europeans, as well as the American Indians, knew how to render copper hard. The copper of these ancient people was always impure, very likely in consequence of the composition of their ores. Their bronze-metal contains always more or less tin, lead, zinc, arsenic, silver, and gold. The hardening extended frequently through the body of the metal, but generally it was confined to the surface.

A remarkable difference is perceptible between the alloys of copper and those of iron in respect to hardening. Iron alloys, and most others, become hard on being heated and suddenly cooled, while copper alloys become softer by such an operation. Compression has a similar effect on these alloys, as on all other metals—it renders them hard.

Copper and lead unite only to a certain extent: 3 lead and 8 copper is ordinary pot metal. All the lead may be retained in this alloy, provided the object to be cast is not too thick. When the cast is heavy, or much lead is used, it is pressed out by the copper in cooling. One lead, two copper, separates lead in cooling—it oozes out from the pores of the metal: 8 copper and 1 lead is ductile, more lead renders copper brittle. Between 8 to 1 and 2 to 1 is the limit of copper and lead alloys. All of these alloys are brittle when hot or merely warm.

Alloys of copper are subject to the same laws as others; and as they are generally more tenacious, more use is made of them. Phosphorus renders copper very hard, brittle, fusible, and oxidizable. Clean copper, held in the vapors of phosphorus, is successfully hardened. A very little of this substance melted together with copper, causes it to be very hard, similar to steel. Carbon combines with copper and causes it to be brittle. Silicon also combines with it, hardens it, and, if present in a small quantity only, does not impair its malleability. Arsenic has only a faint affinity for copper; still the last traces of it cannot be driven off by mere heat; the combination is brittle. Equal parts of copper and silver, and 2 per cent. of arsenic, form an alloy similar to silver, a little harder, however, but of almost equal tenacity and malleability. Antimony imparts a peculiar beautiful red color to copper, varying from rose-red in a little copper and much antimony, to crimson or violet when equal parts of both metals are melted together.

Uses.—The application of copper, either in its pure condition or as an alloy, is so universal that but little can be said on this subject. It is used for sheathing and bolts for ships, for boilers in factories, distilleries, dyeing establishments, steam-boilers, &c. Rollers, shaft-bearings, engraver's plates, and kitchen utensils, are manufactured of pure copper or its alloys. For cylinders, water-pumps, coins, wire, and a multitude of purposes it is also used. Its oxides form fine colors, but are deadly poisons.

The quantity of copper manufactured in the world may be from 25,000 to 30,000 tons annually. Of this amount the United States furnishes about 4,000 tons, and England 16,000 tons. The remainder is smelted in Russia—which furnishes generally very pure metal—Sweden, Germany, South America, and other countries.

Manufacture of Copper.—Smelting of copper is an extremely simple process, because it is as permanent as iron, and little affected by heat and oxygen. Most of the American copper is smelted from the native copper of Lake Superior. The metal which occurs mixed with gangue, consisting chiefly of silicious rock, is cut into small lumps that may enter the furnace; these are in some instances of a ton weight and more. Or, if the metal is disseminated through the mass of the rock, either in grains or in small veins, it is pounded and washed in a stamping-mill, and the contents so far concentrated that the sand contains from 70 to 75 per cent. of copper. This is called stamp-work, and sent in barrels from the mines to the smelt-works. Copper from this kind of native metal is smelted in Roxbury, Mass., Pittsburg, Chicago, and other places, chiefly in reverberatory furnaces. There are also a number of small blast-furnaces in the western States, where copper is smelted. For smelting it thus, from stamp-works or lumps, any reverberatory furnace may be used, either of those in which copper is refined or smelted, or a roasting furnace may be easily converted into a smelting furnace. The operation is simple, and will be described under refining of copper.

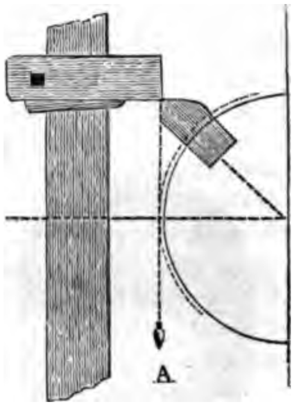
Smelting in Reverberatory Furnaces.—There are two distinct methods of smelting copper ores; the one is in reverberatories, and the other in blast furnaces. As the operations are similarly conducted in the various countries where they are practised, and as the smelting of copper ores in reverberatories is done with skill and much experience at Swansea, Wales, we will first describe the operation as it is there performed.

In all instances the copper ores are sorted at the mine, the lumps broken, and large pieces of rocky matter thrown away. The ore is then classified in various qualities, of which the impure ore is sent to the stamps to be crushed and washed. Clay ores are broken into small pieces and washed by hand. All the rich ore, or that ready for smelting, is broken with the beater to lumps of the size of nuts, and freed from light impurities by riddling.

The small and impure ore is washed with a sieve in water, which carries away the stony parts and leaves the metalliferous ore in the tub. Those parts of the ore which are very impure, but will pay for crushing and washing them, are sent to the stamping-mill.

The stamping-mill is the same as that formerly described, and is represented in fig. 352. The ore is here converted into powder, more or less fine, and separated from gangue in the labyrinth or slime-troughs; or, the ore is washed on the sweep-table, shown in fig. 353. In fact the purifying of copper ore does not essentially differ from that of other ores. But as the specific gravity of copper ore is small, much care should be taken not to crush it very fine in the stamps.

FIG. 352.



The furnaces used in this operation are five in number; they are all of similar construction, and so far all the various operations may be performed in the same furnace, at different times. Still it is found to be profitable to divide the operation, and perform it in different machines. In fig. 354, A, is shown a plane, and in B a vertical section of a reverberatory calcining furnace. This furnace is not essentially different from those shown in previous engravings. The vault C is an addition; into this the ore is discharged when calcined. The furnace is constructed partly of fire and partly of common bricks, and strongly bound. The hearth

D is from 18 to 19 feet long, and 14 to 16 feet in width. The fire-grate is 5 by 3 feet. The fire-bridge is hollow, and through it fresh air is conducted to the ore under treatment. Two hoppers serve for letting in the ore. The chimney is low.

Fig. 353.

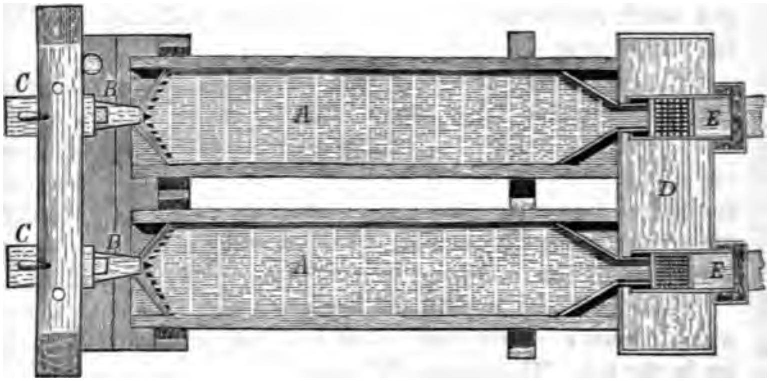
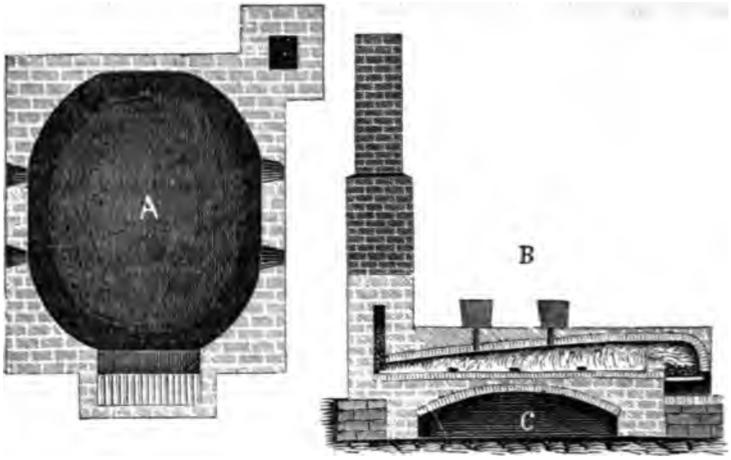


Fig. 354.



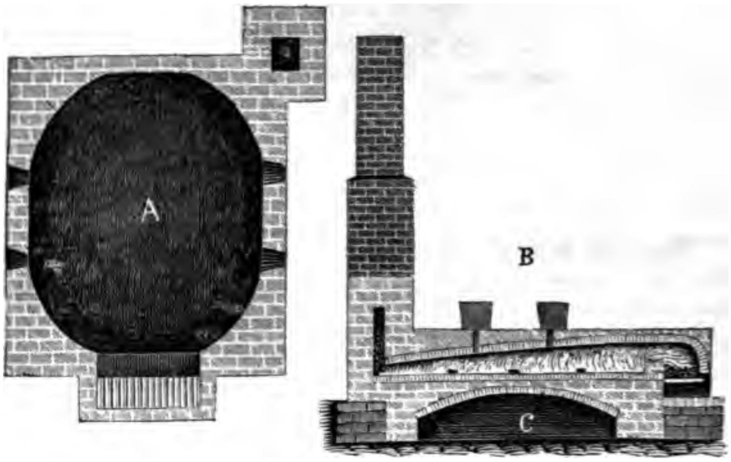
The first process is the calcining of ore. Three and a half tons of clean ore are charged into the furnace at a time, which is, with occasional stirring at intervals of 2 hours, ready to be withdrawn after a heat of 12 or 15 hours, and let into the cab—vault—beneath. Here it remains as long as possible in a close heap, at least so long as the vault is not needed for the next charge. When the ore is withdrawn it is spread evenly on a floor and damped. In this operation it loses much of its sulphur, and after being cold and wetted is ready for the next operation.

The second process is the smelting of the ore. The furnace for this purpose is much smaller, only 11 feet long, and 7 or 8 feet in width. The grate is as large as the one in the calcining furnace, because a higher heat is here required. The furnace has only one work-door at the flue, and in one side a similar aperture for cleaning the hearth. The hearth is formed of coarse sand, and slopes slightly towards the door in the side. Below this door there is an iron grating which covers a vault of water, into which the metal is discharged and granulated. A hopper is placed in the top of the furnace for letting in the charge.

A charge in one of these furnaces consists of 21 to 24 cwt. of roasted ore, which takes 4 hours for smelting, adding slags from refining, and also fluxes, if such are necessary. Two cwt. of slags are generally charged with the ore, besides lime, fluor-spar, or other fluxes, according to the quality of the ore. The time of smelting these charges is 4 hours, after which the slag at the top of the metal is skimmed off by means of a rabble, and drawn out at the work-door into a bed of sand. The metal is not drawn at every heat, but only once or twice each 24 hours. A second charge of ore is therefore thrown into the furnace, after the poor slags are removed; the furnace is then shut once more and that charge melted. When the metal, which is matt, an alloy of all the metals in the ore, and sulphur, rises as high as the bridge at the work-door, the tap-hole below is opened and the matt either run into the basin of water below the furnace for granulation, or into a bed of damp sand. The metallic grains which are thus formed oxidize rapidly, particularly on their surfaces. The color of this crude metal is a steel-gray, its fracture compact, and it is of much lustre. The scoria rejected after this process contains always some metal; copper and tin are found to be present in 1 or 2 per cent. in this silicious slag. The matt produced, contains about 33 per cent. of copper, or 4 times as much as the ore; the other 66 per cent. is chiefly sulphur and iron. If with the use of the refining slags the ore does not flux, the addition of fluor-spar is resorted to. Great care must be taken not to use too much of these fluxes, for all scoria, no matter of what description, will contain copper; and the more slag there is made, the greater must be the loss in metal. The size of the smelting furnace is so regulated, that it consumes all the ore which is calcined in the first furnace.

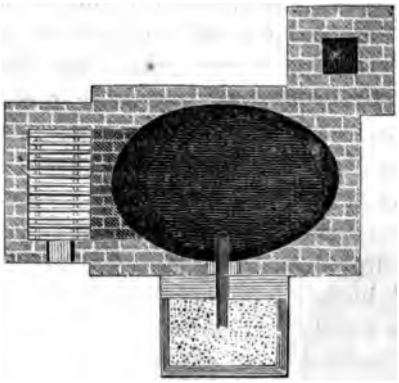
The third operation is that of smelting the crude metal, or matt, of the second process, with the slags of the fifth process. This slag is chiefly a peroxide of iron, and the operation may be called on this account a roasting one. This calcination is performed in the large furnace, represented in fig. 355. The charges consist of 2 tons of matt, with nearly an equal amount of slags. The operation lasts 24, and sometimes 30 or 36 hours, under repeated puddling of the ore. In this process much care must be taken to regulate the heat; it should be performed on the principles of roasting by commencing with a low heat, which is gradually increased to the melting point. The ore is tapped into the vault under the furnace, and oxidized by exposure.

FIG. 355.



The fourth process. This is again a smelting operation performed in the smelting furnace, of which fig. 356 shows a plan. The charges are 28 or 30 cwt., and a heat lasts from 5 to 6 hours, or when slow 8 hours. At every charge the metal is tapped, which now is a rich matt of 66 per cent. of copper. It is frequently very pure, and then it is called fine metal, and run into moulds, forming pigs; sometimes all of it is pimpled copper. In this operation there should be still so much sulphur in the metal, as to cause sufficient fluidity; if there is a lack of it, some green ore is charged with the matt. When the metal from this operation is far from the reguline state it is run into water and granulated.

Fig. 356.



The slags from this last smelting, together with some other slags, are sometimes melted in a furnace by themselves, which forms a particular operation. The matt obtained from these slags is a white and brittle alloy. The slags are also partly thrown away, but most of them are used in the first process. The matt obtained is smelted separately, and then added to the first smelting, or the second operation.

Fifth process. The fine metal in the form of pigs of the foregoing operation, is charged to the amount of 2½ or 3 tons at once in the calcining furnace, and exposed for 24 hours to a gentle heat. It should not melt, at least not for 16 hours, and when melted afterwards it is to be repeatedly skimmed. The metal from this calcining operation is drawn into a bed of sand, and formed into pigs, which are fine metal for the refining furnace.

The sixth process, is that of refining or toughening the metal. This operation is done in the smelting furnace; a charge of metal is from 3 to 5 tons. The pigs are exposed in the furnace to a roasting heat for 12 or 16 hours, then the charge is melted, skimmed, and worked as clean as possible. A test of the metal is, after 20 hours' heat, taken by means of an iron ladle. A small wrought-iron foundry ladle is washed and heated in the fluid copper until it becomes red-hot, or as hot as the metal itself. A ladle full of metal is now taken from the furnace and exposed to a slow cooling in the air. If the copper is fine enough, it will settle considerably in the ladle. The surface of the metal in the furnace is now covered with fine charcoal and prepared for refining. If the copper in the ladle swells up, or shows veins, or black spots, it is not fine enough. In order to accelerate the process, a pole of wood is now used for stirring the metal diligently for ten minutes, after which another ladle full is taken for trial; it is now found to be fine, it will settle in the ladle. Good fine metal is brittle, of a deep color, coarse grain, porous, and crystalline. The surface of the melted copper is now covered with fine charcoal, and the metal repeatedly stirred by means of wooden poles. The grain of the copper becomes finer by this operation, and the metal tougher. A test of the metal is now repeatedly taken in a small iron ladle, and when considered sufficiently refined, it is tried by means of a hammer on the anvil, while still red hot. If the metal forges soft, does not crack on the edges, and the refiner considers color and grain sufficient, it is ladled out of the furnace with large ladles and cast-iron moulds. These form either pigs or slabs, 12 inches wide, 18 inches long, and 2 or 2½ inches thick. These slabs are ready for the rolling mill.

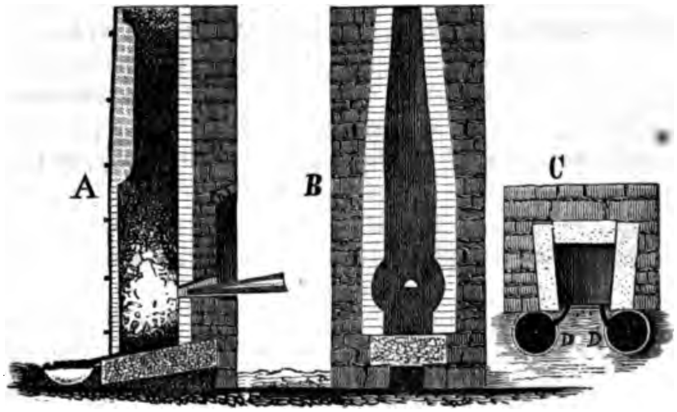
In the progress of these different operations, the use of the slags forms a remarkable point for consideration. From the last smeltings the slags go back to the first process, to be either calcined or smelted. The refining slags are smelted with the metal in the formation of matt; and those from the smelting of matt are used in the calcining operation. The arrangement is such that the slag from the last operation is returned to a previous one. In each smelting some of the slags are thrown away, as too poor for the further work of extraction.

The fine metal of the sixth operation, should be blistered or pimpled metal, containing from 94 to 96 per cent. of copper. Pimpled metal always assumes blisters, like those on converted steel, when cast into a sand-bed. The heat on the fine or blistered metal is longer or shorter according to its purity; an impure metal requires more heat than a pure metal. In some instances, but a few hours roasting are sufficient, in others a longer time is required. When the copper is melted in the refining furnace there is no harm done in stirring and cooling it, alternately, so as to chill the metal, and then melting it again. The rabbling, or puddling, must be continued until the copper is fine; in this operation the foreign metals become oxidized and vitrified. The slags of all the various operations contain more or less copper, particularly those of refractory ores. Neglect in skimming causes the slags to absorb and retain much metal. The slags of the coarse metal, or matt, take up the oxides of iron and tin, and often contain 5 per cent. of copper, they are therefore re-smelted. If the ore contains much tin, antimony, lead, and other metals, the slags of the fourth operation are smelted in a slag-furnace, and the metal obtained, used as pot-metal, either for brass and copper nails, or if much tin and lead is present, pewter is formed of it.

When the point of refining is passed, in the operation of refining copper, the metal deteriorates in value, it becomes carbonized; this is prevented by exposing the hot surface to the action of the flame, and in skimming charcoal and slags off. Good metal is bright on the surface in the furnace. It is of a fine red color when cold.

In the Blast Furnace.—The other method of smelting copper ores is in the blast-furnace. The ore for this operation is sorted, washed, stamped, and in fact prepared as lead or silver ores. Poor ores, such as copper stists, are roasted in heaps, for 15 weeks or longer. In smelting, matts are formed as in reverberatories, which are resmelted, and finally refined. In fig. 357, two vertical sections, A and B, are shown of a blast-furnace, and in C, the plane section with its two basins D D. The height of the furnace is about 14 or 15 feet; the widest part of the boshes 39 inches; the hearth is 2 feet square. The basins, D D, are 3 feet in diameter, and about 21 inches deep.

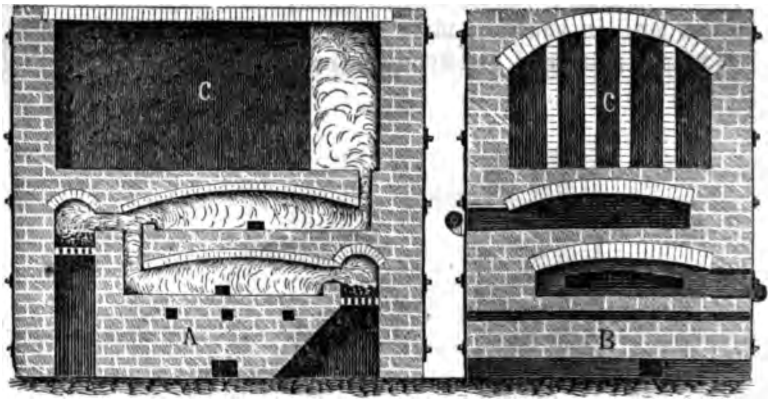
Fig. 3.



The copper ores, after having been roasted, are smelted by charcoal or coke, anthracite is perhaps preferable to either. The tuyere is generally pushed far into the furnace, so as to concentrate the heat in its centre. About 4 tons of ore are smelted in 24 hours with a considerably strong blast. In this operation a matt and a slag are smelted; the first contains from 30 to 40 per cent. of copper, and the latter frequently 5 or 6 per cent. more or less, according to the kind of ore. The matt contains sulphurets of copper, iron, silver, zinc, arsenic, cobalt, and in fact all those metals which were originally in the ore. It is tapped alternately into the basins, and the slags removed from its surface. In cooling, it forms on its surface round plates which may be lifted from the fluid metal. These contain matt of a variety of compositions according to the height of the metal in the basin.

The matt thus obtained is generally roasted, either in kilns, or more generally at present, in reverberatories, of which fig. 358 A, represents a vertical section of a German one. Fig. B shows the same furnace in an opposite section to that of A. Above the two furnaces, there is a condensing chamber C, into which the volatile metals are conducted. These two furnaces, one above the other, are so arranged, that either of them may be used separately. The flame is then conducted from the lower furnace in a separate flue into the condensing chamber, the partitions in which are so arranged that the gases are conducted from one into the other until they escape into a chimney.

Fig. 358.

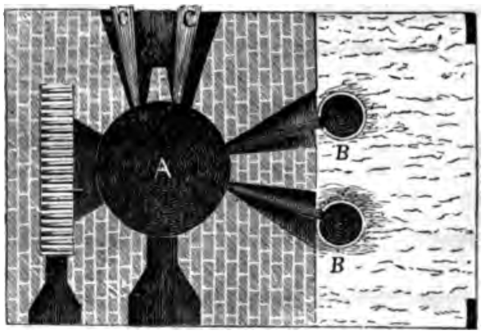


The matt is roasted in these furnaces from 3 to 6 times; this is, therefore, an extremely slow operation; subsequently it is exposed to smelting again in the blast-furnace. Crude copper is now obtained of a granulated fracture, which is ready for refining. After the above-mentioned roasting is performed, the ore is lixiviated in water, in order to extract the soluble sulphate of copper, which is precipitated by means of metallic iron. The coarse or black copper forms the lowest stratum in the smelting furnace, and also the basins; above this floats a poor matt covered by a silicious slag, which is thrown off and rejected. The matt and the metal underneath, are gradually lifted out as it cools, and are in the form of rosettes.

The fine copper, thus obtained from the blast-furnace, is most generally refined in reverberatory furnaces. In all instances that copper which has been smelted in blast-furnaces is subjected to refining in the reverberatory, if it is brought into market directly from the blast-furnace; this kind of copper is quite impure, which renders it unfit for being rolled into sheets. The impurities are most successfully removed in the reverberatory, as they consist chiefly of carbon and oxidizable metals.

A copper refining furnace, as it is used by the Germans, is shown in fig. 359 in plane. The hearth A, 7 feet in diameter, is formed of sand, or clay and fine charcoal. B B are two receiving basins, for ladling out the copper, or forming rosettes of it. Three tons of black copper are melted at once, and as soon as the metal is fluid the bellows are set in operation, which, by means of the tuyeres, C C, furnish blast on the surface of the metal and oxidize it rapidly. A thick slag is thus formed which is constantly drawn off, so as to expose a clean surface to the action of the blast. The refining lasts about 16 or 17 hours, and the loss of metal amounts

FIG. 359.



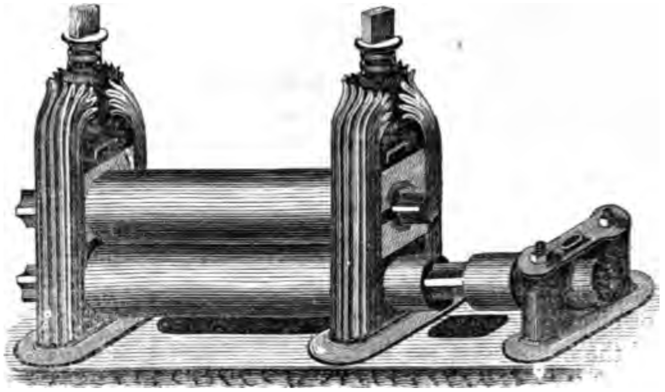
to 3 per cent., which is absorbed by the slags. The latter is returned to the blast-furnace.

The expenses for smelting copper ores are high, on account of the many and tedious operations which must be performed. Poor sulphureous ore, or that which contains but 8 or 10 per cent. of copper, is the most profitable in the reverberatory; rich ores should be smelted in the blast-furnace. Ores of 9 per cent. consume 20 tons of mineral coal for the production of 1 ton of metal; poorer or richer ores than these cause the use of still more fuel. The labor spent in working the ore, amounts to still more than the fuel consumed, and it may be near the truth when we state that a ton of copper smelted of ore requires the labor of 80 men for one day. The price paid for poor pyrites, is $2 50 per cwt., so that a ton of ore yielding 10 per cent. of copper is worth $25. Rich ores are not paid for according to this standard, because they cause the use of more labor and fuel.

Copper is brought into market in different forms. For melting brass it is sold in a granulated form, bean-copper. This is produced by pouring it through an iron strainer, made of a ladle, into cold water. Hot metal causes round beans, cold metal oblong beans. Russian copper is sold in small square slabs; Spanish copper in the form of pigs.

The rollers used for laminating copper or brass are plain cylinders, as shown in fig. 360, not often more than 36 or 40 inches

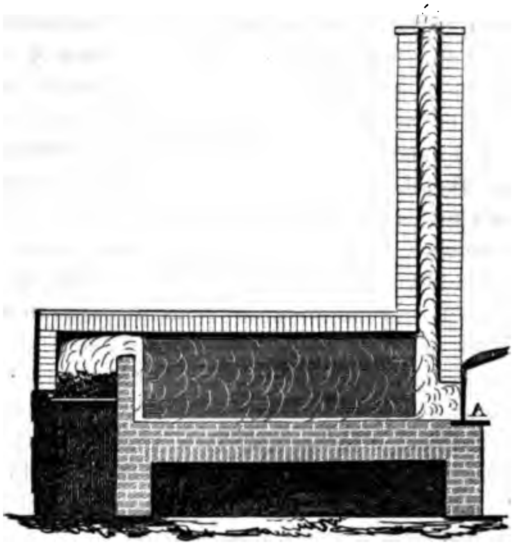
Fig. 360.



long, and 16 inches in diameter. Rollers 5 feet long and 20 inches in diameter, are used for large sheets. Slabs for rolling, are gently heated on the hearth of a reverberatory furnace, fig.

361, to a dull red heat. At first singly, and as the sheets become thinner, they are passed in pairs, or three sheets and more at once, through the rollers. In the process of lamination the metal becomes cold, and by compression hard; it is therefore reheated, which serves in the mean time, when performed slowly, for annealing. When large sheets are to be rolled, the annealing furnace must be of a sufficient size to contain them. They are greased before passing them between the rollers. Most of the sheet copper manufactured in the United States, is produced in Connecticut, Massachusetts, and Pennsylvania.

FIG. 361.



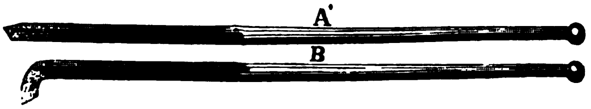
Some kinds of copper contain large quantities of silver, for which the Lake Superior copper is particularly distinguished. We shall allude to the extraction of this metal under the head of silver.

Theory of Smelting Copper.—The copper of commerce is not pure; it is an alloy, as well as other metals. A quality of Norway copper, much esteemed by brass manufacturers, contains 99·5 copper and ·5 lead. Hard Hungarian copper contains 99 copper, ·7 antimony, ·1 iron. A superior quality of Swedish copper was composed of 98·66 copper, ·75 lead, ·05 iron, ·23 silver, ·05 silicon, ·02 aluminum, ·03 magnesium, ·12 potassium, and ·09 calcium. These assays show how much impurity copper may contain, and still be considered as a good article. The purest kind of copper should be employed for sheets. A minute quantity of lead causes copper to roll badly, and iron causes it to be brittle. Other admixtures are less injurious than these metals. We are informed that the purest copper contains protoxide of the metal, a fact which is observed in most other metals. The best kinds of copper are those which have been smelted by charcoal, and contain minute quantities of potassium. Bell-founders and other workers in bronze and brass are in the habit of covering the metal with potash or soda; this causes it to be close, sonorous, and of a fine grain. The substances most injurious to copper are lead, iron, antimony, silicon, carbon, sulphur, phosphorus, arsenic, and some other. Small quantities of lead, iron, nickel, silver, aluminum, magnesium, calcium, sodium, and potassium, improve the tenacity and general qualities of the metal. In refining copper, it must be, therefore, of advantage to have the surface of the metal covered with charcoal which has been soaked or damped with a solution of carbonate of potash or soda. These alkalies cause the removal of lead, tin, zinc, and iron, and prevent the flying or boiling of the metal.

The fine copper of the smelter, pimpled copper, black copper, or blistered copper, is an impure copper which contains much iron. This kind of metal is so far purified copper as to show its color and faint metallic properties. Black copper, smelted of pyrites, contained 95·7 copper, 2·9 iron, ·6 zinc, and ·8 sulphur. Some crude copper, smelted of carbonates and oxides, in the blast-furnace, was composed of 89·3 copper, 6·5 iron, 2·4 peroxide of iron, ·3 sulphur, and 1·3 silica. We may mention that silica, combined with the protoxide of iron, exists in the form of slag in the copper. A coarse metal, which was derived from a refining cinder, contained copper 27·6, iron 2·5, cobalt 19·7, nickel 35·2, lead 12·4. A metal which furnished a prime quality of copper, in refining it, consisted of 95·5 copper, 3·5 iron, ·4 bismuth, ·6 silver.

The composition of the crude metal depends on the composition of the ore. In metal derived from sulphurets, much sulphur is found; and in that from oxides, other metals form the impurities, which must be removed before the metal is saleable. Iron forms, in most instances, the bulk of the impurities, and it must be the object of the refiner to remove it entirely. The presence of silica is required to oxidize and remove iron; but, as the oxide of copper has also a strong affinity for silica, the heat should be low, and the iron-slag, as soon as formed, should be removed by skimming the metal. In crude copper, derived from pyrites, the iron may be supposed to be present as sulphuret; and as, in oxidizing this, the metal is oxidized to the highest degree, it is necessary that carbon should be present, to reduce the peroxide of iron thus formed, and convert it into protoxide, suitable for a union with silica. Such crude copper should therefore be refined, under cover of charcoal, agitated by means of wooden poles. Copper smelted of oxides contains the iron in a metallic state, in the form of grains; for the affinity between these two metals is so faint that they do not unite chemically. The proper mode of refining this kind of crude copper is to melt it at a pretty strong heat, and stir or puddle it by means of an iron rod, or hook, such as shown in fig. 362. Other substances than those above mentioned are easily removed from copper. Lead, zinc, bismuth, and arsenic are volatile, or their oxides combine readily with potash or soda, by the addition of which they will separate from the metal. A small quantity of precious metal does no harm to copper; and large quantities, such as one per cent. of silver or gold, may be profitably extracted from it. Cobalt is removed with the iron, and nickel does no harm, for the alloy may be used as argentan in case much of this metal is present. When iron chiefly is to be removed, a clean surface of the melted metal is required in order to facilitate its oxidation; all other metals ought to oxidize slowly, and the oxides should be supplied with some alkali to combine with.

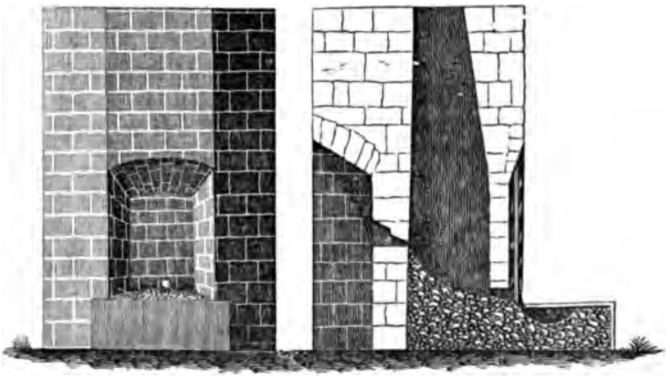
Fig. 362.



The impurities of copper are brought into the metal either by the ore, flux, or fuel. Iron is generally used as flux; if there is not sufficient of it present in the ore, it is added in smelting. But, as this method of using iron causes the formation of balls or lumps of refractory metal, or slag, in the furnace, the poor copper ore which contains iron as a natural admixture is preferred, since it is not liable to balling. The iron is in sulphuretted slags, in the form of sulphuret of iron. In slags derived from oxidized ores, it is in the form of protoxide. In the first kind of slag, sulphur causes its fusibility; in the second slag, silica. The former is a sulphuret, the latter a silicate. Both these compounds may be present in a slag; this, however, is not often the case. Generally, the silica separates from the sulphuret, and, as the first is not so heavy as the latter, it floats on its surface. In smelting, we thus obtain a slag which is a silicate, as the highest stratum, and a slag which is a sulphuret below that; the latter is called matt. When metals are present which have only a faint affinity for sulphur, such as lead, gold, or silver, these gather below the matt and slag, as we have seen in smelting lead. So long as sulphur is present in the slags, we cannot succeed in removing all the iron from the copper, nor all the copper from a sulphureous slag. Silicate of copper is refractory. All the metal may be extracted from a silicate, provided the union of copper and silex is prevented. The metal should be separated before silex is admitted to act on its oxide. Thus we have a series of operations in the reverberatory, all calculated to remove iron by means of silex, and retain and concentrate the copper in the form of a sulphuret or matt. The addition of silica to rich ores is, therefore, a necessity; but, as it is difficult to estimate the proper quantity to be used, such rich ores are not always so profitable to work as the poorer kinds. Too much silex causes a stiff cinder which absorbs copper; and too little silex does not absorb all the iron, and forms a stiff slag which cannot be separated from the copper, and causes it to form balls and oxidize. In smelting copper, as well as other metals, the slags are never too fusible; stiff pasty slags always retain grains of metal. It makes no difference by what means copper slags are rendered fusible, provided they melt at a lower degree of heat than the metal itself. Copper cannot be reduced from its sulphuret—it should be oxidized; therefore, the smelting of copper is divided in a succession of processes, consisting of alternate calcinations and smeltings.

Slag from a smelting of copper pyrites in a reverberatory contained 48·2 silica, ·5 protoxide of copper, 37 protoxide of iron, 3 oxide of tin, 4 lime, 1 magnesia, 1·8 alumina. This slag is thrown away, because it contains but little copper. Slag from roasted pyrites, smelted in a low blast-furnace, contained silica 51·8, protoxide of copper 1·4, protoxide of iron 29·2, baryta 8·8, alumina 5. The same kind of ore, smelted with more iron, furnished silica 35, protoxide of iron 41, oxide of zinc 3, baryta 12, lime 3, magnesia 2, alumina 4. This composition furnishes a more fluid slag than the former, and is consequently free from copper. When the addition of iron is necessary, it should be made in the form of forge cinder, or puddling-furnace cinder, from the iron works; because that form of iron fluxes well, without furnishing metal. The following is an assay of a slag which contained too much iron: silica 33·6, protoxide of copper 3, protoxide of iron 51·5, lime 5, alumina 5·6. This slag, besides containing much copper, caused the deposition of considerable iron in the smelted copper, which formed balls of refractory metal consisting of 89·4 iron, 2 copper, 7 cobalt, and 1·8 sulphur. We thus see that the quantity and form in which fluxes are used, is of much importance in this operation. Copper may be smelted from crude ores with success, as it is performed in Sweden; but the operation requires skilful hands to manage it. The fluxes are arranged so as to form a silicate, consisting of silica 56·5, protoxide of iron 14·9, lime 6·3, magnesia 14·3, alumina 6. This is a first-rate slag, and works well in the low blast-furnace. The flux commonly used is limestone and forge cinder. More lime and less iron causes the copper to be very impure, and the slags contain copper; it also causes vexatious work in the furnace. Slags from copper smelting resemble the forge cinder of the iron-works; they are however generally not so glassy, and often contain oxide of iron not combined with silica.

FIG. 363.



The matt obtained in the various processes is a compound of metals and sulphur, differing with the kind of ore from which it is obtained and the mode of operation by which it is formed. Roasted pyrites smelted in a low blast-furnace, such as is used for smelting lead, fig. 272, furnishes a matt consisting of 27 copper, 40 iron, 25 sulphur, and 8 earthy matter. Rich matt, smelted in a blast-furnace 16 feet high, from roasted ore, contained 58·6 copper, 13·2 iron, 23·2 sulphur, and ·6 earthy matter.

The slags obtained in refining-furnaces are a combination of the oxides and sulphurets which are contained in the crude metal. Refining is at present exclusively performed in reverberatory furnaces, either with the assistance of blast or without it; in either case the metals are oxidized by the oxygen of the air, and the sand of the hearth furnishes the silica for vitrification. These slags always contain a large quantity of copper, and are therefore re-smelted, either by themselves, or returned to earlier operations. The predominance of other metals than iron in the slags is indicative of a corresponding quantity of copper. Oxide of antimony is particularly apt to form and absorb oxide of copper. Lead has a similar effect, but in a far less degree. The slags obtained from the refining operations are easily reduced in a small blast-furnace, and furnish an alloy. Smelted in a crucible with black flux, an assay of them is obtained in which all the other metals are present except iron. Their appearance varies greatly; when they contain much iron and sulphur, they are gray or black. Slags which contain no sulphur are brown, semi-transparent, and often blood-red, magnetic, of all shades of color between black-brown and light-red.

On whatever principle the extraction of copper from its ores is conducted, the composition of the ore and flux is so arranged that the yield does not amount to more than 7 or 8 per cent. The first smelting yields then a matt of 30 per cent. of copper; the second smelting one of 60 per cent., and the third smelting crude metal, or pimpled copper of 75 to 85 per cent. In blast-furnaces, ores of 2½ per cent. or less in yield, may be smelted to advantage. Rich ores are smelted in a low furnace, the height of which varies from 5 to 18 feet. The first smelting of a 2½ per cent. ore yields, in Sweden, in the first smelting a matt of 60 per cent. of copper. And the second smelting, after roasting the matt, yields crude metal of 85 or 90 per cent. copper. In Germany, an argentiferous copper is smelted of bituminous slate in high blast-furnaces, which yields only from 1 to 3 per cent. of copper; the copper has not quite ¾ per cent. of silver. In all these various forms of smelting copper ore, a rapid oxidation by a high heat cannot be permitted in order that the formation of silicates of copper may be prevented. Calcining is performed at a low heat, because if the ore was subjected to fusion in the operation, much copper would unite so closely with the silica as to become inseparable in the smelting-furnace. Sulphur and silica are necessary fluxes in the reverberatory. In the blast-furnace, copper ore may be smelted by fluxing it with lime or silicate of iron; and where the latter can be obtained in sufficient quantity, there is no doubt but that the smelting is cheaper when performed in the blast-furnace than in the reverberatory. Refining should be invariably done in the reverberatory.

CHAPTER VIII.

Gold.—*Germ.* gold; *Fr.* Or; *Lat.* Aurum. Gold is found almost over the whole globe, but in most cases in small quantities compared with other metals. At the present time California affords the largest amount of this metal in the world. Virginia, North Carolina, South Carolina, Georgia, and Alabama, in the United States, afford gold in considerable quantity. The production of California amounted in the year 1850 to about $40,000,000 worth of this metal; the other States of the Union together about $2,000,000. Next to the United States, the largest amount of gold is furnished by Russia, from the Ural Mountains. It is found extensively in the South American States, near the Equator, in Africa, Asia, and Europe. Gold is chiefly found in its native condition, in a metallic state, alloyed with silver, and sometimes with tellurium, as is the case in Virginia and North Carolina. In California it is found chiefly in alluvial ground, bedded upon rock in most cases; it is also found inclosed in quartz rock, apparently in veins ramifying the rocks of an extensive mountain range. This California gold is obtained chiefly in large grains, and often in lumps of several pounds weight. In the other States of the Union the gold is in very minute fragments, often invisible to the eye if not aided by a lens, only to be detected by crushing and grinding the rock and washing off the debris. This gold is apparently derived from the decomposition of iron and copper pyrites, chiefly the first; which assertion cannot be objected to, because it is founded in principle that almost all iron pyrites contain gold, that the gold ores of that region are rocks which are colored by iron, and that this iron is evidently derived from the decomposition of the pyrites. Pyritous ores of this kind are worked which contain no visible gold, or which do not yield gold at the first crushing and washing, but which furnish gold in a succession of amalgamations, performed after regular intervals of exposure to the air in a fine powder. Gold is also furnished by the silver ores of North Carolina and Virginia.

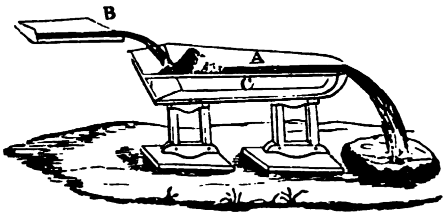
A splendid yellow color and brilliant metallic lustre characterizes gold distinctly from other metals; its specific gravity being 19·3 to water, is another quality easily appreciated by the senses. It is pre-eminently ductile, which qualifies it for an extensive use in the arts. One grain of gold may be drawn into a wire 500 feet long; silver may be coated with gold, of which the thickness is only the twelve-millionth part of an inch, and still the microscope cannot detect the slightest indication of an interruption of the gold coating. Pure gold requires more heat for melting than either silver or copper, but as all native gold is alloyed with some other metal, it may be considered more fusible than those metals. If, in cupelling gold, the hot globule shines with a greenish light, we may consider the gold not much adulterated; if it contains 10 per cent., or from there to one-third of silver, the color of the gold is in the hot cupel white as silver. Pure gold is not very volatile, and may be exposed to a strong heat for a long time without loss of metal; but if gold is alloyed with volatile metal, such as lead, zinc, and antimony, it is liable to be carried off by their vapors. Gold has a considerable cohesion, which inclines it to crystallization. Its crystal form is an octahedron; it is often found in fragments of crystals imbedded in quartz, of which fine specimens are found in California, and also in the gold region of the Southern States. In melting gold along with pure borax it assumes a whitish color, as if adulterated with silver; in melting it again with saltpetre, or common salt, it recovers its rich yellow color.

The geological position of gold is in the primitive rock. It is found in granite, disseminated in grains and spangles through the mass of rock. In the United States gold is chiefly found in the stratified transition series; in California it appears to be disseminated through this rock, imbedded in quartz. Most of the gold, the California gold exclusively, is found in alluvial soil. In the Southern gold region this source is much exhausted, and the gold is here obtained from regular, well-developed veins, running parallel with the general direction of the rock strata, southwest by northeast. The plane of inclination of these veins is also parallel with the plane of inclination of the general formation. It appears from this that the gold-bearing veins are of a simultaneous origin with the rock; at least, they have been introduced when the rock was in a plastic condition. In Virginia and North Carolina the gold-bearing veins are a ferruginous talcose slate, often inclined to mica slate. In North Carolina this slate is found to be very hard in many instances, showing a compact solid mass of rock, apparently the same slate, but having been under the influence of a considerable heat, it is hardened. In Virginia this slate is more soft, the fissures open more readily, and the whole vein shows the appearance of soft slate. This slate is impregnated with small quartz veins, from one-eighth to one-half an inch, and often two inches thick. Where these quartz veins are thin and in great numbers, the ore is always found to be richest in gold. This feature of the ore is well developed throughout Virginia, and at Goldhill, North Carolina. The veinstone of the gold-bearing veins is strongly impregnated with oxide of iron, showing evidences that this iron is derived from pyrites, because the oxide appears in dots or flowers, and groups of dots. Many of these veins have been traced to that depth where the pyrites are not oxidized; here they appear in their perfect crystal form, and are profusely distributed through the slate. The oxidation of these pyrites appears to depend on the penetrability of the rock by atmospheric agents; where the slate is soft we find it oxidized to the depth of from 50 to 150 feet; where the slate is hard, as is the case at the Sawyer mine, North Carolina, the oxidation reaches hardly 10 or 20 feet deep, and is in many places, such as bluffs, not developed at all. At the latter spots the pyrites are in their original form, untouched by oxygen. Where the pyrites are not oxidized the extraction of gold is connected with considerable more expense than it is from soft slate and oxidized pyrites. The crushing of the hard slate is in the first place more expensive; the sulphur of the pyrites destroys a large portion of quicksilver in amalgamation, and the gold cannot be all extracted; the largest portion of it remains inclosed by the sulphuret of iron, which can only be liberated by destroying that envelope.

When we consider the great extension of the Southern gold formation, which is at least 500 miles long; the breadth of the gold-bearing strata in which the veins are imbedded, and which is from 5 to 20 miles wide; further consider the depth of these veins, which may be assumed to be 2,000 feet, the body of gold ore in these regions is certainly to be regarded as an important source of national wealth. There is, however, one drawback to the rapid extraction of gold from these deposits—the ores are all, without exception, pyritous in greater depth, and to work these sulphurets to advantage no progress has been made up to this time. Various experiments tending to accomplish this purpose, and affording means of extraction, have been tried, but none of these succeeded so far as to work the poorer class of ores. At Goldhill, N. C., where the ores yield from $1.50 to $3 of gold in 100 pounds or one bushel of ore, the pyritous ores are ground, amalgamated, and a certain portion of gold extracted. The crushed ore, now a fine sand, is exposed to the influence of the atmosphere for one year, after which the process of grinding and amalgamating is repeated, and another portion of gold, almost equal to the first, is extracted. An exposure of another year furnishes another crop of gold, which operation may be repeated four or five times without extracting all the metal from the sand. This way of working is tedious, expensive, and will not answer where the ores yield but 25 cents to the bushel. The process of roasting these ores by artificial fire is too expensive, and all processes which require much labor are out of the question. Here is a promising field for American ingenuity and industry.

The extraction of gold is performed in California, and also in some parts of the Southern States, simply by washing the alluvial soil, removing the sand, clay, and debris of rock; after these operations the gold, as specifically the heaviest matter, will remain in the vessel in which the washing has been performed. This washing may be done to advantage in a tin pan or a sheet-iron pan. Such a pan is filled with sand containing the gold and immersed in water; in stirring it gently by hand the clay and light sand flow off, and, after some of the earthy matter is removed, the pan is shaken so as to bring the heavier gold to the bottom of it; the superstratum of sand is now removed, and the gold found in the bottom of the pan. Where water is abundant, a more effective machine than the pan is employed. This machine is called a rocker. It is represented in fig. 364.

FIG. 364.

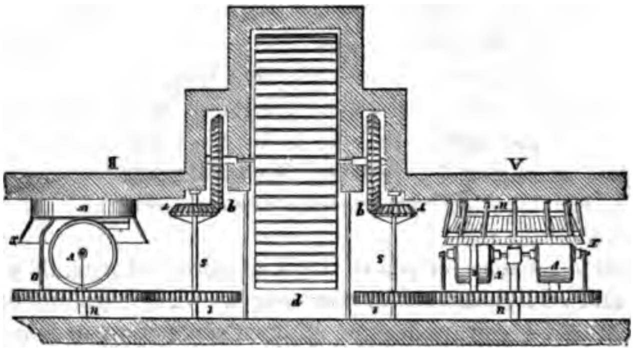


This is a machine made of wood, about 6 feet long, 26 inches high, and 16 inches wide in the trough. A is a grating of flat iron bars, set edgeways, leaving an open space of about ½ an inch between each bar. By B a strong current of water is let upon this grating, which flows off at the opposite end of the machine. The machine rests upon two gently-curved frames, which admit of a rocking motion upon two planks laid on the ground. This apparatus is set in a rocking motion by a boy, two wooden springs on each side of it limiting that motion, and forcing the rocker back at each vibration. The machine represents in its motion a worn-out cradle, which is used beyond gentle rocking. A laborer supplies the rocker with sand at B, by means of a shovel; the sand which passes through the grating, and also the gold, falls in the trough C, in which quicksilver is kept in case the gold is fine; it forms here an amalgam of gold. The light sand from C is swept off by the water which passes through the grating. The cradle is more or less inclined towards the discharge of the charges, according to the kind of material to be washed. These operations are quite effective; secure, for coarse gold; the fine and floating gold is lost.

Gold inclosed in rocky matter cannot be washed with success in the foregoing described manner; the rock must be crushed, and is, in this operation, transformed into more or less fine sand. The bulk of this sand is removed by washing, and the rest, with the gold, reserved for amalgamation.

The crushing is performed in the stamp-mill, fig. 365. A vertical shaft, to which a cross shaft and two millstones of 4 or 5 feet diameter are appended, revolves slowly around itself, making from 3 to 5 revolutions per minute. This shaft carries with it the two head-stones, which revolve around the vertical axis, and in the mean time around their own axis, running upon a third millstone, which is laid horizontal, and fixed upon the floor of the millhouse. These stones are of hard material, either of granite, gneiss, trap, or some other tenacious hard rock. Such mills are chiefly used for grinding clay, fire-clay, or kaolin in porcelain manufactories. Similar mills are exclusively employed in North Carolina for crushing gold ores, also to some extent in Virginia; they are there entirely constructed of iron, or at least the facing, or grinding part of it is made of cast-iron; and are here called Chilian mills. These mills show one advantage to the stamper mills; that is, they may be made to grind the ore very fine; and where that is necessary, as it is with many gold ores, these mills are advantageous. But there is one serious drawback to these machines: they require much power in proportion to their effect, and much room. A strong mill of this kind requires from 4 to 6 horse-power, with which it will grind from 40 to 50 bushels of ore in 12 hours, that is, ten bushels to a horse-power. One horse-power will drive one stamper in a stamp-mill, and that stamper will crush at least 30 bushels in the same time,—a consideration which is of importance where wages, power, and time are valuable.

FIG. 365.

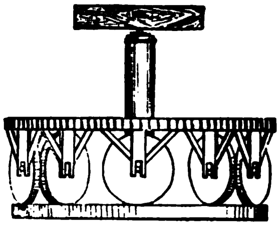


After the crushing is performed, the sand, including gold, is conducted over hides, which retain the gold, and the sand is floated away. The gold and sand from the hides are removed, when the latter are filled, to an amalgamating machine, which combines the gold with quicksilver, and admits the sand to flow off. Instead of hides, woollen blankets are also used for gathering the gold, and there is a diversity of opinions as to the merits of either. Blankets, it is contended, are more expensive than hides, but they have the advantage of working more uniform. Hides are cheaper, but they lose their hairs or wool very soon, and are then not fit to do good work. Hides of short, curly wool are selected; these are spread on the ground, and over these the water, sand, and gold are led in a broad sheet. In other instances shaking-tables are suspended at the discharge of the stampers, which gather the gold and some sand. Shaking-tables are wooden platforms of 8 or 10 feet long, and from 3 to 4 feet wide, made of 2-inch plank well joined together, and the whole smoothly planed. Around the edges of the table are projecting ribs, which prevent the water from flowing over the edges. In suspending this table, a little inclined to the horizontal, leading the sand and water over it in a broad sheet, and applying a gentle shaking motion to it, the gold will sink to the bottom and move gently down the plane; it is arrested at the lowest end of the table by a projection on the table. In either of the above cases the gold is brought to the amalgamating machine for amalgamation.

Most of the gold-mining establishments are provided with Chilian mills for crushing the ore. We furnish a description of it in its simplest form in fig. 365, in which form most of these machines are erected. Still, there are some machines of this kind in North Carolina, which work by four or five runners or crushers in one trough.

In fig. 366 is such a machine represented as it is in operation at Goldhill. It is a cast-iron circular trough of about 16 feet diameter, 10 inches wide, and 6 inches deep; the trough is firmly fixed upon the floor of the mill. In this trough five travellers or head-stones are moving, of 3 feet diameter and 6 inches thick, rounded on the edge, made of cast-iron. These travellers are

FIG. 366.



fixed to the revolving-shaft in the centre, and are moved by it. The circular trough is supplied with coarsely broken ore and a constant current of water, which latter washes off all the light impurities, and leaves the gold in the trough. At the close of every day's work the trough is supplied with some quicksilver, which is worked in it for ¼ or ½ hour's time, in which time it absorbs the gold, and is then removed as amalgam. The water from these mills is generally conducted into other machines, in which some of the fine gold which passes from the first machine is gathered. In most cases a shallow round basin, of about 4 feet diameter, is appended, in which a rake moves around with a vertical axis, gently stirring the sediment which may settle from the passing water. It retains only the heavy particles. In other instances, Sullivan bowls (a small machine which derived its name from the inventor, residing in North Carolina) are appended; these gather the heavy parts which may escape the previous machines.

A Sullivan bowl is represented in fig. 367. A vertical wooden shaft of about 18 inches long and 2 inches square carries on the lower part a shallow vessel or bowl B, about 2 inches deep and 18 inches in diameter. This bowl is formed of a wooden bottom and sheet-iron periphery. This bowl receives the water from the other machines at or near its circumference, and discharges at the centre. By the lever A, the machine is set in a rocking motion, caused by a crank connected with the same. This machine gathers a great deal of fine gold, but it is an expensive machine, because they work but little water, and it requires many machines to do the work of a small establishment.

Fig. 367.

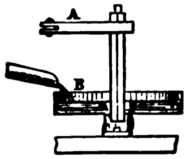
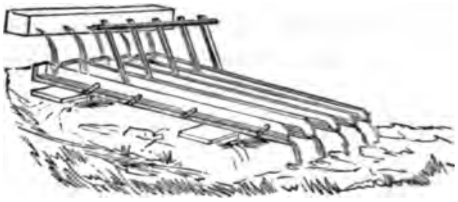


Fig. 368.



The gold from the various machines, mixed with some sand and other impurities, is carried to the Chilian mill for amalgamation, in case there is no other machine for doing that work. This is an imperfect machine for amalgamation, and causes losses in quicksilver and gold. In most cases separate machines are used for amalgamation; in North Carolina the cradle is generally employed. The cradle is made from the trunk of a tree, hollowed out so as to form a round trough, closed at one end and open at the other, as represented in fig. 368.

Here is a battery of 5 cradles represented: as many as that are frequently connected and moved by a little boy. A cradle is from 10 to 12 feet long, hollowed out of a trunk of at least 24 inches diameter. The bottom part is thicker than the sides. The first cradle in the drawing shows a section. We see here three or more grooves carved in the bottom; in each of these grooves from 3 to 4 pounds of quicksilver are put. At the farthest end sand is shovelled in and water led upon it, the cradles being a little inclined towards the discharge. A gentle current of water will have a tendency to wash sand and every thing else down the trough, the trough being, in the mean time, in a rocking motion, which assists the water in washing off every thing. The quicksilver in the grooves is also in constant motion, by which the heavy granules of gold gliding down on the bottom are arrested by it, while the lighter matters, as sand, &c., are not attracted, and pass over the mercury. These machines are very effective, but work slow, and lose much of the fine suspended gold. Other amalgamating machines have recently been put in operation; their efficacy is, however, not settled, and we hesitate to describe them. In North Carolina the German barrel amalgamation has been introduced within a few months, but we are not informed of the results. In Virginia, amalgamating machines of novel patterns have been tried, but we are not acquainted with their effects.

All amalgamating machines suffer under a common evil—they cannot work all the water as it issues from the crushing machines to advantage. In all instances half the golden contents of the ore are lost. This is owing partly to the clayish condition of the ore, which clay incloses particles of gold and carries it off, and partly to the extreme division of the gold in the ores of these regions, particularly in North Carolina. This minute division causes the gold to be suspended in water, and in that condition it is carried away by the current. A good amalgamating apparatus, which will work the water directly from the crushing machines, rub off clay and other matter from the particles of gold, so as to make it adhere to the quicksilver, and which does not lose any quicksilver, is still a desideratum in the Southern gold-mining districts.

Gold, gathered by quicksilver, forms a white amalgam. In the amalgamating machines a surplus of quicksilver is used to secure the fluidity of the mercury; for if it gets slimy, or still worse, plastic, like clay, it will not absorb any more gold with facility. The fluid amalgam is pressed through a soft leather or a piece of close canvas, to remove the superfluous mercury; after which a solid amalgam, called quick, remains in the bag. The quicksilver which passes through the bag retains always some gold in solution, the quantity of which varies according to the stuff through which it has been squeezed. The amalgam thus obtained contains from 30 to 70 per cent. of gold, according to the mode of working and the quality of the ore. The quick from the Chilian mills generally contains but from 30 to 40 per cent. of gold, while that from stampers contains seldom less than 40, and in most cases from 50 to 60 per cent. of gold. This circumstance appears to speak in favor of the stamps; the difference in the contents of gold, in the amalgam, is owing to its division; the finer the gold the less of it the amalgam contains. The dry amalgam is distilled in an iron retort, lined with clay; a red heat will drive off the mercury, which is condensed by leading it into cold water. The gold remains in the retort in the form of a powder, which is collected, melted in a crucible along with some saltpetre, and cast into iron moulds, forming square bars of about one pound weight each. One pennyweight of gold of the Virginia mines is generally worth from 90 to 92 cents. North Carolina gold contains more silver than the first, and a pennyweight is seldom more than 90, and in the majority of cases, from 80 to 90 cents to the pennyweight. California gold ranges from 75 to 90 cents.

In Virginia and North Carolina gold ores are mined, crushed, and amalgamated, which yield but the 150.000th part of gold to the bulk of ore, and these ores are worked with profit. The Russel Mining Co. in North Carolina, which operates 12 or more Chilian mills, works ore which yields 10 cents of gold to the bushel, or 100 pounds of ore, with profit. The Louisa Mining Co., which employs stampers for crushing, shows that ores which yield 7 cents in the bushel may be worked, and pay expenses and profit. There are inexhaustible stores of gold ores in the Southern States; it requires nothing but industry to make its production profitable.

Silver.—Argent, *Fr.;* silber, *Germ.;* argentum, *Lat.* Native silver is frequently found; it appears crystallized, but chiefly in irregular concretions, often in the form of fine hairs. Generally it is combined, or alloyed, with gold, quicksilver, antimony, arsenic. It appears as sulphuret in connection with the sulphurets of most other metals.

Pure silver is the brightest of the metals, of a beautiful white color and rich lustre. Its specific gravity is 10·47. It is a little more fusible than gold, but in practice we find it generally the reverse, which is owing to the alloys of the two metals, which have a more softening influence upon gold than upon silver. Silver is exceedingly malleable, but not so much as gold; it crystallizes very readily when exposed for some time to the influence of heat in a melted state, but not so when alloyed to other metals. This latter quality of silver has been made available in practice, in refining lead for silver. If silver bearing lead is exposed to a melting heat, the silver will not crystallize along with some lead. Lead crystallizes more readily in this case, and these crystals may be removed from the fluid mass by an iron dipper pierced with small holes. The crystals of lead, thus freed from the largest part of their silver, are melted and converted into pigs and sold. After repeated melting and crystallization, the remaining fluid is rich in silver, and is now refined in the common way.

Silver ores are of great variety: there is antimonial silver, found in Mexico and Europe; sulphuret of silver, almost every where; also the mixtures of sulphuret of silver, with other metallic sulphurets; chloride, carbonate, and tellurate of silver are curiosities of little practical value. Most of the silver, and in the United States exclusively, is derived from the sulphuret of lead, from galena. In the Union we have but one establishment which manufactures silver to some extent; it is the Washington Mining Company, in North Carolina. As the production of silver from its ore is generally conducted on the same principles, and as the operation at the Washington mine may be considered one of the most difficult cases, on account of the composition of its ore, we will describe the operation in this instance.

The ore at this establishment consists chiefly of brown sulphuret of zinc, which is largely mixed with galena, copper, and iron pyrites; it contains silver, gold, and other metals. The ore as it comes from the mine is broken into coarse fragments, and roasted in heaps in the open air, in the manner described before. The roasting is performed altogether by wood and wood charcoal. After the first roasting the piles are picked over for such ore which is well roasted, and that which is too much roasted. This is brought to the stampers, crushed into a fine powder, and washed, so as to carry off all the oxidized zinc and quartz. If the ore, after its being crushed, is found to be imperfectly roasted, it is returned to the yard and once more subjected to roasting. That part of the ore which is rejected in the yard is piled and roasted along with some fresh ore from the mine. In this way it may happen that some of the ore is exposed to several heats. The roasting operation is not considered to be finished until all the sulphuret of zinc is destroyed; that is, until the zinc is deprived of its sulphur and converted into oxide of zinc, in which form it may be washed away by the water at the stamping-mill.

The finely powdered ore consists now chiefly of galena, or, in case the roasting operation is well performed, of oxide of lead, oxide of iron, oxide of copper, silver and other matter. This ore is brought to the smelting-furnace, called a high-furnace, and here smelted along with some fluxes by charcoal. In fig. 370 such a furnace is represented; it is a solid work of masonry, calculated to retain its heat if once thoroughly heated. The fire is urged by cylinder bellows, driven by a steam-engine; the air to the fur-

FIG. 369.

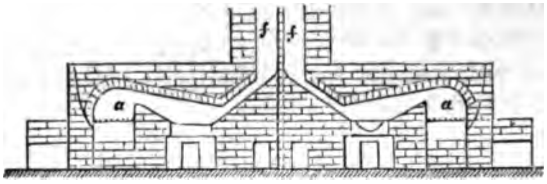


FIG. 370.

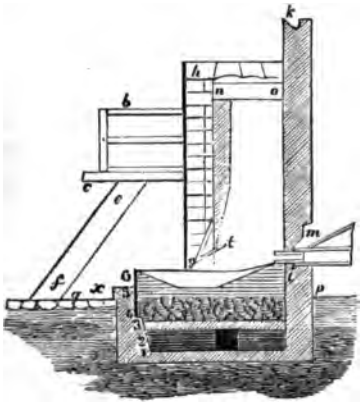
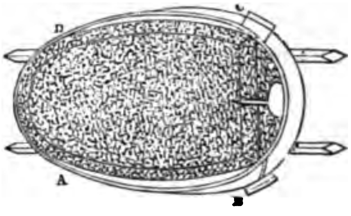


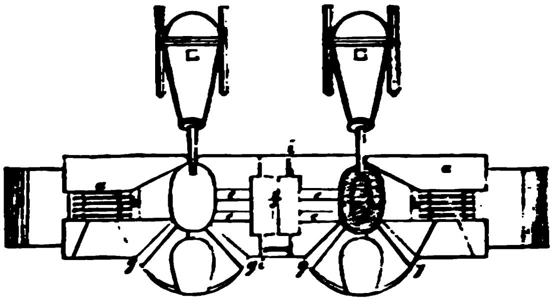
FIG. 371.



nace is supplied at the tuyere *m*. In consequence of the alternate charges of coal and ore, the basin or hearth *g* is regularly supplied with metal, which is removed at certain intervals of time, so as to afford room for fresh metal and cinder. In this manner about one ton of lead is obtained in 12 hours, which is removed and put aside for refining. The composition of the ore, which makes its perfect roasting difficult, renders it necessary to make large additions of iron ore to the posts of ore. The iron oxide, which is reduced in presence of carbon in the furnace, will absorb the sulphur from the other metals in case there is any sulphur left after roasting. This circumstance renders the operation tedious and slow. It cannot be avoided but by perfect roasting, which may be considered practically impossible in this instance. The presence of zinc is what renders the operation tedious and expensive. If the zinc is not removed to a large extent, it will, in smelting the ore, carry off by evaporation much of the other metals, gold and silver not excepted. The sulphurets of zinc and lead are very fusible if in contact. In roasting the ore these two sulphurets will invariably melt together, which causes the roasting process to be either very expensive or imperfect. All experience with a similar ore in other parts of the world are confirmatory as to this operation being expensive.

The lead from these blast-furnaces is transferred to the refining-furnace. Formerly the English refining-furnace was used as it is represented in fig. 369, in a longitudinal section. Here is a double, or two furnaces represented, which, as is shown, are reverberatory furnaces. The fireplace *a* throws the flame over the hearth or cupel into a chimney, which is provided with a sliding door at *f f* to shut off the draft and prevent the fumes of metal from escaping through the stack. The cupel is formed of several layers of bone-ashes, mixed with wood-ashes; this mass is rammed into an iron hoop when in a moistened condition. The form of this cupel is represented in fig. 371; from above it is a concave egg-shaped dish, of about 5 inches thick, the largest diameter being 4 feet, the smallest 2 feet. When the furnace and cupel are heated, the lead, previously melted in an iron pot, is cast into it; and now the bellows, which are represented in fig. 372, are set to work, a gentle current of air is thrown over the hot surface. The action of the blast is here twofold; it oxidizes the lead and forms litharge of it, and drives by its force the melted litharge to the opposite side of the blast, or the tap-hole, where it flows out and falls into an iron basin, from whence it is carried back to the smelting-furnace. The level of the lead is in this way gradually reduced if not kept up to a certain height; this is done

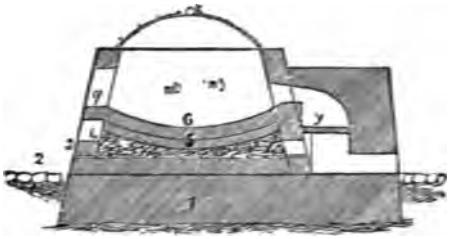
Fig. 372.



by casting in melted lead, which is always ready melted in an iron pot. This process is carried on until a certain quantity of lead has been concentrated so far that a little more than one weight of lead is combined with an equal weight of silver: this rich lead is taken out and refined in a properly prepared cupel. If sufficient rich lead is ready to make from 500 to 1000 ounces of silver, it is refined in a new cupel, and the silver melted into a cake. The operation is carried on as before with the only difference, that no fresh lead is added.

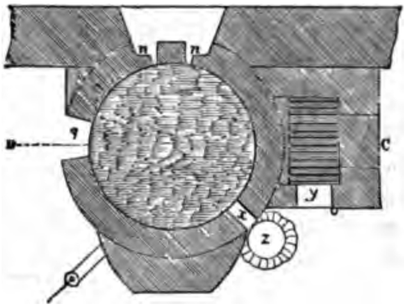
The Washington mine has more recently introduced the German refining-furnace represented in fig. 373, with what success

Fig. 373.



we are not aware. This furnace is larger than the above English furnace, the cupel being at least 6 feet diameter. The drawing shows a section of the furnace, in which the fireplace *y*, the tuyeres *n n*, and the door *q*, into which the lead is charged, are shown. In fig. 374 is a ground plan of the furnace shown. Here is the flue *x* visible, which leads to the stack, and which serves in the mean time to clear off from the surface of the melted lead some of the scum. The cupel of this furnace is made entirely of wood-ashes, which are the refuse ashes from the soap-works, and in this respect the furnace has an advantage over the English furnace. The floor or hollow surface of it is well pounded by wooden mallets, to make it solid and smooth. About four tons of lead are charged for one heat; it is carefully laid upon the bottom, and at first gently heated, so as not to injure the fresh bottom and dome. When the lead is melted, and all ebullition ceases, the blast is thrown in at the tuyeres *n n* by setting the bellows at playing on the surface of the melted metal. At first no litharge is made, but a dirty froth of oxidized metals is raked off, to facilitate which formation of froth, fine charcoal dust is thrown on the surface. When all the impurities of the lead are removed in this way, the formation of litharge begins, which flows off at the flue *x*. The separation of the litharge from the lead must be assisted by a hook, because the blast is generally not strong enough to move the fluid oxide of lead over the large surface of the molten mass. The cupellation of four tons of metal lasts from 18 to 20 hours. Toward the end of the operation some silver is carried off with the litharge, which portion of litharge is therefore carefully preserved, to be remelted by itself or along with other ore. The silver is, in this operation, obtained pure in the first heat; it is melted into the form of a cake in a cavity prepared for its reception in the centre of the hearth.

Fig. 374.



In all these refining operations there is an inevitable loss of metal, disappearing in the form of fumes, through the chimney.

This loss is variable, and may be modified by the skill of the workman and the purity of the lead; it amounts on an average to from 4 to 7 per cent. of the lead melted.

The extraction of silver from its ores by amalgamation is not practised in the United States; this process requires rich ores and cheap quicksilver. In the old States of the Union there is no prospect of seeing this process executed; but in California, where rich silver ores and mercury ores abound, there may be a probability of its being executed; still it is a tedious, expensive operation, which, at the rate of wages paid in the United States, will not yield much profit. Amalgamation is a process not adapted to our social condition; it is too laborious to secure success in ordinary cases of common or average ore. For these reasons we do not furnish a description of this operation. In our condition there is no way of working silver ores profitably but by smelting the ore and refining the lead; or, in some instances, the new process introduced last year into European establishments may answer our purposes.

Some of the silver smelt-works of Germany have been in a condition of working poor ores, which, in many instances, have not covered the expenses of smelting or amalgamation, which must be extreme cases, considering German industry and perseverance. A process has been introduced within a short time, which promises to advance the interest of the metallurgy of silver greatly. The operation is as follows: Silver ores which may be poor or contain more or less silver, are coarsely broken or stamped, and then carried to a reverberatory furnace; here the ore is heated to redness, calcined, and in that state from 2 to 5 per cent. of common salt is added to the ore; the whole kept in that degree of heat, and stirred by iron bars for some hours. The object of this operation is to transform the silver contained in the ore into chloride of silver, which is so much more easy, as silver has a predominating affinity for chlorine. If the operation of heating is perfected, the red-hot ore is drawn from the furnace and thrown hot into a boiling concentrated solution of common salt. The hot salt solution will dissolve the chloride of silver, and it is kept in solution so long as that solution is boiling-hot; it is therefore necessary to filtrate it in this condition. To the hot and filtrated solution a little muriatic acid is added, and then some coarse pieces of crude copper; which latter precipitates all the silver in a metallic state, in the form of a fine powder: this is gathered and melted in a crucible; it is pure silver. This process is, to all appearances, simple, and is in fact so; but it requires an expert chemist to execute the operation. If there is only copper, iron, and silver present in the ore, the operation is simple; but if there is gold, lead, or quicksilver in the ore, the case is not so easily managed; for the gold will not pass with the silver into the solution, and the chlorides of lead and quicksilver, which are soluble in the same manner as chloride of silver, are precipitated by the same means. The application of this process to our Southern ores is difficult, but it may be an extremely useful process in applying it to the argentiferous stamp-work of the Lake Superior copper ores.

The silver ores of the Southern gold region, such as are smelted at the Washington mines, yield from 200 ounces to 300 ounces of silver in a ton of lead; the ore itself contains on an average 8 per cent. of lead; the other matter is zinc, iron, copper, tin, and chiefly sulphur. The silver is worth $1,80 the ounce, because it is alloyed with a large portion of gold, which raises its value to double the value of pure silver.

Mercury.—*Syn.*, quicksilver; *Germ.*, quecksilber; *Lat.*, hydrargyrum, has been known from early historical times. The most important mines used to be, and are still, in Spain; besides which, mercury is made in Idria and Western Germany, in Mexico and California. This subject is of more importance to the United States, since the acquisition of California, than it was previous to that time; not only in respect to the manufacture of the metal itself, but in its relation to the gold and silver ores. The quicksilver mines of California had been worked before its annexation, but these mines never attracted so much attention as they have done since that country became a part of the Union. The principal mines in California are the Guadalupe and the New Almadan mines, which are some miles distant from each other, and not far in the interior of the country. The ore in these places is a beautiful sulphuret, cinnabar, of a bright, fiery-red color, and yields from 60 to 70 per cent. of mercury. The successful operation of these mines, and a reduction of the price of quicksilver in consequence, is an important object to the silver mines of California, Mexico, and, in fact, to all the silver mines along the Pacific coast.

The extraction of quicksilver from its ores is a very simple operation: but, as economy is desirable in all operations of this kind, we will describe the most perfect apparatus invented for this kind of work—it is that constructed by Dr. Andrew Ure for a European establishment of this kind.

Fig. 375 shows a section of a furnace parallel with the front elevation represented in fig. 376 *a a a* are iron retorts; the whole furnace contains 9 of them. I is the fireplace, designed either for coal or wood. The upper retort is protected against the direct contact of the flame by fire-bricks. K K shows the flues for the escape of the burnt gases. The whole arrangement is shown in fig. 377 very distinctly. The two ends of the retort, *a*, are shut by two iron lids, secured by cross-bars and screw-bolts, luted with clay. The one end of the retort is provided with an iron pipe *b*, which leads into a long condenser *e*, and from thence into the receiver D, *e*. The hole L is designed for the introduction of an iron wire, in case any disturbance should happen in the pipe *b*, where dirt from the ore may accumulate and obstruct the passage of the mercury vapors. The pipe, *c*, is always partly filled with quicksilver, and kept cool by water contained in a trough which surrounds it.

FIG. 375.

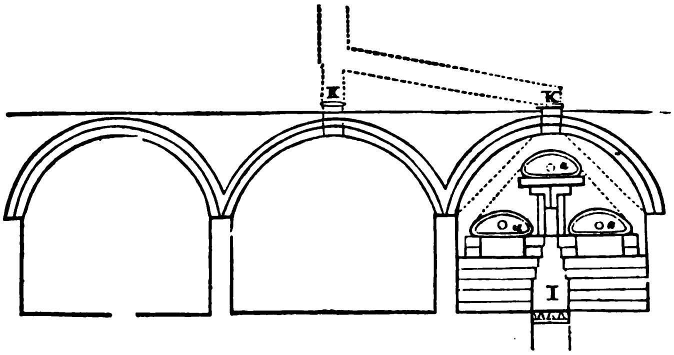
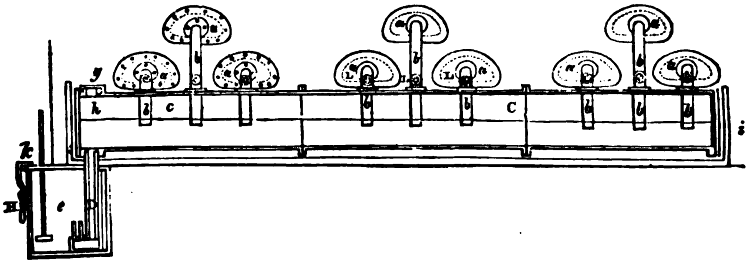
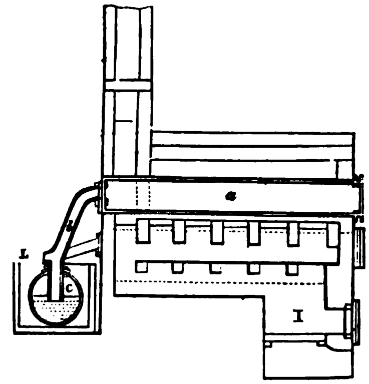


FIG. 376.



The retorts are kept in constant ignition, and a charge is worked in three hours' time, each charge consisting of 5 cwts. of ore. The ore is finely broken, and mixed with a portion of quicklime or porous magnetic iron ore, and, if it can be had, with both mixed together. The quantity of lime or iron depends upon the quality of the ore; pure ore requires more of it than impure ore. The quantity of quicksilver made in one retort per day depends also on the richness of the ore: the California ore ought to produce at least 600 lbs. in 24 hours in one retort, which will be for 9 retorts nearly 2 tons and a half per day. The retorts are charged and discharged from behind, so as to leave the condensing apparatus undisturbed.

FIG. 377.



Platinum is a metal of a grayish-white color, resembling in a good measure polished steel. It is harder than silver, and of about double its density, being of specific gravity 21. It is so infusible, that no considerable portion of it can be melted by the strongest heats of our furnaces. It is unchangeable in the air and water; nor does a white heat impair its polish. The only acid which dissolves it, is the nitro-muriatic; the muriate or chloride thus formed, affords, with pure ammonia or sal ammoniac, a triple salt in a yellow powder, convertible into the pure metal by a red heat. This character distinguishes platinum from every other metal.

The cavities of the rough grains are often filled with earthy and ferruginous matters. Their specific gravity is also much lower than that of forged pure platinum, and is owing to the presence of iron, copper, lead, and chrome; besides its other more lately discovered metallic constituents, palladium, osmium, rhodium, and iridium.

The whole of the platinum ore from the Urals is sent to St. Petersburg, where it is treated by the following simple process, described by Dr. Ure.

One part of the ore is put in open platina vessels, capable of containing from 6 to 8 pounds, along with 3 parts of muriatic acid at 25° B. and 1 part of nitric acid at 40°. Thirty of these vessels are placed upon a sand-bath covered with a glazed dome with movable panes, which is surmounted by a ventilating chimney to carry the vapors out of the laboratory. Heat is applied for 8 or 10 hours, till no more red vapors appear; a proof that the whole nitric acid is decomposed, though some of the muriatic remains. After settling, the supernatant liquid is decanted off into large cylindrical glass vessels, the residuum is washed, and the washing is also decanted off. A fresh quantity of nitro-muriatic acid is now poured upon the residuum. This treatment is repeated till the whole solid matter has eventually disappeared. The ore requires for solution from 10 to 15 times its weight of nitro-muriatic acid, according to the size of its grains.

The solutions thus made are all acid; a circumstance essential to prevent the iridium from precipitating with the platinum, by the water of ammonia, which is next added. The deposit being allowed to form, the mother-waters are poured off, the precipitate is washed with cold water, dried, and calcined in crucibles of platinum.

The mother-waters and the washings are afterwards treated separately. The first being concentrated to one twelfth of their bulk in glass retorts, on cooling they let fall the iridium in the state of an ammoniacal chloride, constituting a dark-purple powder, occasionally crystallized in regular octahedrons. The washings are evaporated to dryness in porcelain vessels; the residuum is calcined and treated like fresh ore; but the platinum it affords needs a second purification.

For agglomerating the platinum, the spongy mass is pounded in bronze mortars; the powder is passed through a fine sieve, and put into a cylinder of the intended size of the ingot. The cylinder is fitted with a rammer, which is forced in by a coining press, till the powder be much condensed. It is then turned out of the mould, and baked 36 hours in a porcelain kiln, after which it may be readily forged, if it be pure.

THE END.

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